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**CHAMBERS'S EDUCATIONAL COURSE—EDITED
BY W. AND R. CHAMBERS.**

RUDIMENTS OF GEOLOGY.

**FOR USE IN SCHOOLS
AND FOR PRIVATE INSTRUCTION.**

By DAVID PAGE.

**EDINBURGH:
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1844.**

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W. AND R. CHAMBERS.

PREFACE.

GEOLOGY, in its aim to describe the materials composing the earth's crust, their mode of arrangement, and the causes which seem to have produced that arrangement, constitutes one of the most interesting and important of the natural sciences. Interesting, inas-much as it exhibits the progressive conditions of the world from the remotest periods, and reveals the character of the plants and animals which have successively adorned and peopled its surface; and important, as it determines the position of those metals and minerals upon which the arts and manufactures so intimately depend. Valuable as are its deductions, Geology is comparatively of recent growth, it being only within the present century that accurate data have been collected, and those absurd speculations respecting the origin of the globe eschewed, which had so long impeded the legitimate prosecution of the subject. If, however, long repressed by the imprudence of its early cultivators, no branch of human knowledge has made more rapid progress since right modes of investigation were adopted—none attracted a greater degree of attention, or been more generally applicable to the economical purposes of life. To furnish an outline of the science in its present state of advancement, is the object of the following treatise, in which the leading facts are stated in as simple a manner as is consistent with accuracy. Technical terms, often so ignorantly inveighed against, have not been avoided, but have been gradually introduced with their explanations, to familiarise the learner with Geological language, and thus prepare him for the study of more advanced works, as well as for the practical prosecution of the subject. A uniform arrangement of the topics has been strictly adhered to, so as at once to assist the memory and facilitate reference; theoretical disquisitions have been studiously avoided; and a plain record of facts and observations presented, in order that the treatise might answer the end intended—namely, for Use in Schools and for Private Instruction.

EDINBURGH, *May* 1844.

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GEOLOGY.

OBJECTS OF GEOLOGY.

1. GEOLOGY is that science which treats of the materials composing the earth's crust, their mode of arrangement, and the causes which seem to have produced that arrangement.

2. *By the earth's crust* is meant that external shell or covering of solid matter which is accessible to man's investigation. The highest mountains do not rise five miles above the level of the sea, and the deepest mines descend only about a third part of a mile, so that, even were we perfectly acquainted with the entire space between the top of the highest mountain and the bottom of the deepest mine, it would form but a very insignificant fraction of the distance between the surface and centre of the globe, which is nearly 4000 miles. Thin as this crust may seem, it nevertheless presents innumerable objects for investigation; hence the magnitude of this science, which has been ranked, in point of importance, second only to that of astronomy.

3. *The materials which compose the crust of the globe* are exceedingly varied. For instance, one part of the surface is covered with sand, another with clay, and a third with gravel. How were these materials formed, whence were they derived, and by what agency were they laid down in their present position? Again, shells and bones may be found in the sand and clay, plants and trees in the peat-earth. How came these remains to be buried there, and are they similar to those animals and vegetables now living and growing upon the earth? As we dig through the sands, gravels, and clays, we come upon rocks, some in layers, others in masses;

some are hard and sparkling, others soft and earthy; and most of them differ in colour. Many of them differ also in the kind of matter of which they are composed, such as sandstone, limestone, coal, roofing-slate, &c. How were these rocks formed, and by what means were they laid down in their present positions? for rocks so different in kind as limestone, coal, and sandstone, must have been formed under different circumstances. Further, we find petrified shells, fishes, bones, and plants imbedded in these rocks; and different rocks contain different kinds of these remains. How were they imbedded there? Are they similar to shells, fishes, and plants now existing? Do they seem to have lived and grown in the sea, in fresh water, or on dry land? Such are a few of the questions which it is the province of the geologist to consider; and in doing so, he must ground his reasoning upon the analogy of the changes now going forward on the face of the globe, endeavouring to discover what relation they bear to former changes, and whether both may be ascribed to similar causes.

4. *The causes which modify the crust of the globe* are very numerous, differing in power, as well as in their mode of action. At present we find rivers bearing down mud, sand, and gravel, and depositing the same either along their banks, in lakes, or in the sea—these deposits forming layers of mud, sand, or gravel, which in some cases become consolidated, and assume a rocky appearance. If plants, shells, or dead animals be carried down at the same time by these rivers, they will be imbedded in the layers so formed, and will in course of time become petrified, or converted into stony matter. Rains, frosts, winds, and the like, act upon all rocks, and make them crumble down, thus leaving the decayed matter to form additional surface soil, or to be borne down by rivers and other currents of water. Plants and animals also modify the crust of the globe: plants grow and decay, either adding matter to the soil, or forming accumulations in marshes, in the character of peat-moss: animals also yield their remains to the surface; and some of them, as shell-fish and corals, form vast accumulations of solid matter. Earthquakes break up the earth's crust, elevating some places, and sinking others; raising the bottom of the sea to become dry land, and sinking dry land under the ocean. Volcanoes are sometimes accompanied with similar effects, and generally throw out liquid lava, which, when cooled down, forms rocks; and repetitions of these discharges gradually form mountains.

5. *The causes enumerated in the preceding paragraph* are

those which mainly contribute to the modification of the crust of the globe. In general they act gently, and within limited spaces; occasionally with great violence, and over a large extent of country. These forces have always exerted themselves with greater or less intensity, and have always produced corresponding results. In reference to the masses of sand, gravel, and clay, now far removed from waters, and to the various rocks which are found at great depths in the earth's crust, it is the object of geology to discover whether they are to be ascribed to the operation of forces similar in kind, but greater in degree, than those above-described; and whether the plants and animals found petrified within them be or be not of the same kinds as those now existing. If they are of the same races, did they exist under similar circumstances? and if not, what seem to have been the conditions of the world under which they flourished?

6. *To solve the numerous problems which geology thus embraces*, a vast amount of research and knowledge is necessary. To account for the aggregation and positions of many rock masses, the geologist requires to be acquainted with the principles of mechanics; to treat of their composition and formation, the aid of chemistry must be called in; to describe and classify the remains of plants and animals, he must have recourse to botany and zoology; while, generally speaking, there are many of his problems, for the successful solution of which the assistance of almost every branch of natural science is necessary. An amount of acquirements so varied is beyond the compass of most minds; hence geology has been divided into several departments, which, while ultimately depending on each other for their progress, can be studied as individual sciences. These are—*Physical Geography*, which limits itself to the mere surface and configuration of the earth as occupied by land and water, mountains and valleys, and other external appearances; *Mineralogy*, which treats of the individual crystals or minerals of which rock masses are composed; and *Oryctology*, or *Palæontology*, which directs itself exclusively to the consideration of the fossil plants and animals that may be discovered in the crust of the globe.

7. *Abstract or speculative geology* comprehends all these branches, and, were it a perfect science, would present a history of the globe from its origin and formation, through all the changes it has undergone, up to the present time; describing its external appearance, its plants and animals, at each successive period. As yet, geology is the mere aim to arrive at such knowledge; and when we consider how

difficult it is to trace the history of a nation even over a few centuries, we cannot be surprised at the small progress geologists have made in tracing the history of the earth through the lapse of ages. To ascertain the history of a nation possessed of written records, is a task comparatively easy; but when these are wanting, we must examine the ruins of their cities and monuments, and judge of them as a people from the size and structure of their buildings, and from the remains of art found therein. This is often a difficult, and all but impracticable task; much more so is it to decipher the earth's history. It is true that certain geological facts are recorded; but the record is neither distinct nor of much antiquity. We learn that earthquakes have raised land above, or sunk it beneath, the sea; that volcanoes have formed mountains and buried cities, such as Herculaneum and Pompeii; that the mud of rivers has formed vast plains like the Deltas of the Nile and Ganges; that cities once on the sea-shore are now several miles inland; and that cities once removed from the sea have been washed away by its inroads, their sites now forming the bed of the ocean. Beyond a few facts like these, we have no written geological record; and, for the earlier history of the earth, must descend into the gravels, clays, and rocks which form its crust; judge of past changes by the character of these masses; and reason as to the kind of plants and animals which formerly peopled its surface, from the petrified remains which are entombed in the strata beneath.

8. *The practical utility of geology* is alike varied and extensive. The metals so indispensable to the purposes of civilized life are all dug in the shape of ores from the rocky crust, certain metals being found in certain rocks, and in certain positions. As with metals, so with coal, building-stone, limestone, and other minerals; and it is the duty of practical geology to direct the miner in his search for these valuable metals and minerals, and to point out to him by what means they can be most economically obtained. In a country like Britain, where railroads, canals, reservoirs, tunnels, and harbours are in constant requirement, the deductions of geology must be of first importance in pointing out the kind of rocks through which these operations have to be conducted, as also in ascertaining the strength and durability of the building material required by the engineer and architect. Soils being in many cases composed of the decayed materials, as well as influenced by the porous or compact texture of the underlying rocks, there must subsist an intimate connexion between them; an acquaintance with the prevalent characters of rock formations will, therefore, greatly assist the agricul-

turist in his endeavours to improve the fertility of the soil. Other practical advantages to be derived from the study of geology might be pointed out; but these will be best considered in a subsequent part of the treatise, when, as may be supposed, the student will be better able to judge of their importance.

EXPLANATORY NOTE.

GEOLOGY (Greek, *ge*, the earth, and *logos*, a discourse)—reasoning about the structure of the earth. The term *Geognosy* (from *ge*, and *gnosis*, knowledge) is sometimes used instead of geology, the former signifying absolute knowledge, and the latter implying speculative reasoning. Geology, however, is the term most frequently in use, and is likely to continue so.

CRUST—the outer or solid covering of any body, such as the crust of a loaf, the shell of an egg, &c. The crust generally differs in quality from the internal parts, which it covers; hence the term “crust of the earth” is used to distinguish it from the interior of the globe, concerning which we have no certain knowledge.

PETRIFIED, PETRIFICATIONS (Latin, *petra*, a stone, and *facere*, to make)—to make or change into stone. When a shell, bone, or piece of plant, by being enclosed in rocky matter, becomes hard and heavy like stone, yet retains its shape, it is said to be petrified. Petrification is thus caused by the particles of stony matter entering into, and filling the pores of the animal or vegetable structure; lime-water, for instance, entering into the pores, and between the fibres of a piece of wood, makes it a limy petrification.

FOSSIL (Lat., *fossus*, dug up)—anything dug up out of the earth is fossil; but the term “fossils,” or “fossil remains,” is now generally applied to petrified vegetable or animal remains dug out of the earth’s crust.

ORYCTOLOGY (Gr., *orusso*, to dig, and *logos*, a discourse)—a discourse or reasoning about things dug up. **PALEONTOLOGY** (from *palaios*, ancient, *onta*, beings, *logos*, a discourse)—a discourse or reasoning about ancient beings. Both of these terms are used by geologists to signify the science of fossil remains; some objecting to oryctology as merely referring to things dug up, while common stones are dug up as well as remains of plants and animals; others objecting to paleontology, because, though it refers to *ancient beings*, it does not imply that they are fossil.

STRATUM, plural **STRATA** (Lat., *stratus*, strewn, or spread out). When different rocks lie in succession upon each other, each individual forms a *stratum*; and is so termed from its appearing to have been laid, or spread out in order. Rocks arranged in parallel layers are thus said to be *stratified*; and those among which there is no appearance of this parallel arrangement, *unstratified*.

GENERAL STRUCTURE AND CONDITIONS OF THE GLOBE.

9. Before entering upon the consideration of the materials which compose the external crust, there are certain facts concerning the general structure and conditions of the globe itself, a knowledge of which is necessary to the prosecution of geological research. These are its Figure, Density, Temperature, and Surface Configuration; the Distribution of Land and Water, Constitution of the Sea, the Atmosphere, and Planetary Relations.

FIGURE.

10. THE FIGURE OF THE EARTH is nearly that of a sphere or globe. A diameter (measure through) from north to south is said to be polar; one from east to west, equatorial. If the earth were perfectly spherical, these diameters should be of the same measure; but it has been found by accurate investigation that the polar is less than the equatorial by about $26\frac{1}{4}$ miles. According to Herschel—

The Equatorial is	.	.	.	7925·648 miles.
The Polar is	.	.	.	7899·170 miles.

Difference,	.	.	.	26·478 miles.
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This gives a flattening or compression at each pole of about $13\frac{1}{4}$ miles; so that the figure of the earth is, strictly speaking, that of an *oblate spheroid*.

11. *This polar compression may be artificially illustrated by twirling with rapidity a ball of any yielding material, such as putty, round a spit thrust through it for an axis, when a bulging at the outer surface will take place, causing the ball to lose its original globular shape. This bulging takes place through what is called centrifugal (flying from the centre) force, and creates a difference between the two diameters of the ball similar to that which exists in the terrestrial globe.*

12. *From this spheroidal figure, and what we know of the law of centrifugal force acting upon a body of yielding material, it is concluded that the earth was in a soft or yielding state at the time when it assumed its present form. This is obviously a point of considerable importance in the physical history of our planet, and therefore demands the especial attention of the geologist.*

DENSITY.

13. THE DENSITY OF THE EARTH has also been computed with considerable accuracy. By weighing the most prevalent rocks, it has been found that the solid crust composed of them is about two and a-half times heavier than water; but from experiments made on the attraction of mountains of known bulk, compared with the attraction and bulk of the globe, it has been inferred that the density of the whole mass is five times that of water. In other words, the earth, as at present constituted, is *five times* heavier than a globe of water of similar dimensions, and *twice* that of the rocks at its surface.

14. *The interior or central material* of the earth being thus necessarily heavier than the rocks which form its crust, numerous speculations have been indulged in as to what the nature of these materials may be. It has been said that air, water, or stone, as known at the surface, cannot compose the interior parts; for if the law of gravitation exert itself uniformly towards the centre, either of these would be so compressed as to give the earth's mass a mean density greater than the laws of attraction will allow. Water, for instance, would, at the depth of 362 miles, be as heavy as quicksilver, and air as heavy as water at 34 miles; while at the centre, the density of marble would be increased 119 times! To make their suppositions accord with the mean density of the earth, that is, to reconcile the forces of gravitation and attraction, theorists have successively proposed gaseous fluids, heated matter, and even light itself, as the central material.

15. Laying aside all hypotheses, our knowledge respecting the density and internal structure of the earth may be thus summarily stated:—1. The density of the rocky crust is, on an average, two and a-half times that of water; 2. The mean density of the whole mass is five times that of water; 3. The central parts cannot be composed of similar material with the crust, otherwise their compression would become so great towards the centre, that the mean density of the earth would be much greater than it is; and, 4. That the condensation of the central masses must be counteracted by some expansive influence, such as heat, or have a constitution unlike any substance with which we are acquainted at the surface.

TEMPERATURE.

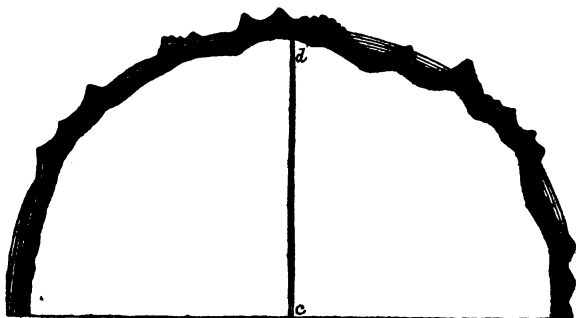
16. THE TEMPERATURE OF THE EARTH is a subject the consideration of which exercises a most important influence on the reasonings of geologists. There is, first, the *surface temperature*, which affects the growth and distribution of plants and animals; second, the *temperature of the crust*, which may give rise to gaseous exhalations, thermal springs, mineral and metallic transformations; and, third, there appears to be an internal or *central temperature*, having its seat beneath the solid crust, and which seems to be the cause of volcanoes, earthquakes, and other similar phenomena.

17. *Of the surface temperature*, we know that it is influenced, first, from day to day, and from season to season, by the heat of the sun; second, by the degree of latitude, being warmest at the equator, and gradually diminishing towards either pole; third, by the distribution of land and water, the sea being less liable to sudden fluctuations of temperature than the land; fourth, by the nature of the surface, the kind and colour of matter variously absorbing and retaining the heat derived from the sun; and lastly, by the elevation of the land above the mean level of the sea, the more elevated being the colder regions. All these influences are at present in active force, affecting more or less the growth and distribution of animal and vegetable life; and in like manner must they have exerted themselves at former periods, though perhaps increased or counteracted by certain conditions not now existing.

18. *The temperature of the crust* may be affected either by heat from the sun, by heat created by chemical action among its materials, or by heat from the interior. During summer, the surface is heated by the sun, and this heat is communicated to a certain depth; during winter, it is again given off to the surrounding atmosphere more or less, according to the severity of the winter. This alternate receiving and parting with heat may differ considerably in any particular summer or winter, but over a number of years it is found to be nearly stationary; that is, the amount of heat received and given off may be said to balance each other. According to this doctrine, the earth in summer will be warmer near the surface than it is at small depths; and in winter will be colder at the surface than at depths beyond the influence of the passing cold.

19. *The heat of the sun can only affect the earth to a limited depth*; for, as the heat of summer proceeds downwards, it is arrested by the cold of winter, and thus conti-

nally kept within a given limit. By actual experiment, it has been ascertained that, at a given depth beneath the surface of the earth, there is a point at which the temperature remains constantly the same, being uninfluenced by any causes which affect the surface. This depth will vary according to the kind of material of which the crust at any given place is composed, be these materials rocks, sand, or water; but in no instance has it been found to be less than 60, or more than 100 feet. A series of these depths, as represented by the white line in the subjoined diagram, is called by geologists the *stratum of invariable temperature*.



Section, showing the stratum of invariable temperature, and relative thickness of the solid crust.

20. Proceeding beyond this invariable stratum, towards the centre (c), it has been found that the temperature gradually increases; a circumstance which attracted the attention of philosophers more than a century ago. In 1802 D'Aubuisson revived the investigation, and since that time, observations have been made in the principal mines of Europe and America. The greatest depths at which experiments have been conducted, are 1713 feet in Mexico, 1584 in England, and about 1300 in Germany; and in all of these the temperature has been found to increase according to the depth. In 1827 M. Cordier published a memoir on this interesting subject, in which he collected the observations of others together with his own; and having made allowance for the heat arising from the breathing of miners, for the combustion of lamps, and communication with the atmosphere, he drew the following general conclusions:—1. Below the invariable stratum, the temperature at any given depth remains perfectly

constant for several years; 2. That below the invariable stratum the temperature goes on increasing with the depth; and, 3. That, taking the average of observations, this increase of temperature goes on at the rate of one degree of Fahrenheit's thermometer for every 45 feet. Others have allowed 60 feet for the rise of one degree; but even taking this lower estimate, it must follow, if the increase go on in the same ratio, that a temperature equal to 100 degrees of Wedgewood's pyrometer would be found at the depth of 160 miles. But, 100 degrees of Wedgewood is sufficient to keep in fusion any of the known rocks, so that, according to this estimate, the solid crust of the earth cannot be more than 60 or 80 miles in thickness—a mere fractional film of the distance from the surface to the centre.

21. *Of the internal or central heat* of the globe, we know nothing by actual experiment; but are left to infer as to its amount from the descending increase of temperature observable in the solid crust, and from the occurrence of hot-springs, vapour fissures, and volcanoes. That the heat of the crust increases as we descend, has been fully established by experiments in mines, in Artesian wells, and in the waters of other deep-seated springs; and if this temperature goes on increasing at the ratio above-mentioned, then the interior parts must be heated to an enormous degree; so much so, indeed, as fully to counteract that law of compression formerly adverted to, and which would render all known matter, if placed at the centre, so dense as to be inconsistent with the mean density of the globe.

22. *Taking all circumstances into account*, the following conclusions seem warrantable:—first, that the interior parts of the earth are heated to intensity; second, that this heat is the apparent cause of volcanoes, hot-springs, and other thermal phenomena; third, that the solid crust derives part of its heat from this source; fourth, that this solid crust has partly been formed by the cooling of an original igneous mass; fifth, that if volcanoes, hot-springs, &c. take place at the expense of this internal heat, the globe must be gradually cooling; but, lastly, that from the bad conducting nature of the rocky crust, this gradual refrigeration is not perceptible within any given time.

EXPLANATORY NOTE.

DENSITY (Lat., *densus*, thick)—thickness or compactness. Density is a comparative term; gold, for instance, being denser than iron, iron than granite, granite than sandstone, sandstone than water, and water than gas; that is, a cubic inch of any one of these bodies would differ in weight from a cubic inch of any of the others. To render this idea of density more definite, water at the temperature of 60 degrees has been

taken as the standard or measure ; hence, if water be assumed as weighing 1, the rocky materials composing the earth's crust will be $2\frac{1}{2}$, or two and a-half times heavier than water.

ARTESIAN WELLS (*Artois*, a district in France)—a term applied to wells sunk by digging or boring perpendicularly through various strata, from the circumstance that this mode was first practised in the district above referred to.

THERMAL (Greek, *therme*, heat)—warm or hot. Thermal and igneous are sometimes used indiscriminately ; but it is more accurate to make a distinction. Thus, in treating of volcanoes, we speak of *igneous* agency ; in treating of hot-springs, *thermal* is the more appropriate term.

TEMPERATURE OF THE EARTH.—The chief of those who have conducted experiments relative to this subject are Gensanne, Saussure, D'Aubuisson, Fourier, Cordier, Quetelet, and Arago, in France, Germany, &c. ; Sir John Leslie, Fox, Forbes, &c. in Britain ; and Humboldt, in Mexico. Their experiments present a wonderful degree of coincidence, and are chiefly of three classes :—1. Those made in mineral veins, or in mountain masses, such as granite ; 2. Those made in stratified rocks, as in coal mines ; and, 3. Those made in Artesian wells and other deep-seated springs.

SURFACE CONFIGURATION.

23. THE SURFACE CONFIGURATION OF THE EARTH is more the study of physical geography than of geology proper ; but it is necessary to observe in what manner it influences the geological changes now in progress. The surface of the earth is extremely irregular, being diversified by hills and valleys, rivers, lakes, seas, &c. Portions of it are covered with woods and forests ; other portions are elevated above the limits of vegetable or animal life, and covered with eternal snows. Some parts of the exposed surface are so hard, that no sensible decay is experienced for ages ; others so soft and loose, that scarcely a shower falls without carrying away a portion to some lower level. These differences of surface material are also influenced by steepness and irregularity of position ; the transporting power of streams and rivers being proportioned to the rapidity of their descent. These are familiar instances of the numerous changes effected by diversity of surface configuration ; but the student has only to cast his eye over his own district, to be convinced how many geological results depend upon this cause. Those immense plains—the steppes of Northern Asia, the prairies of North and the pampas of South America—must affect and be affected in a different manner from the Himmaleh, Alps, Andes, and other mountain ranges. The showers and snows which produce torrents and avalanches on the Alps, form merely springs and harmless streams on the Apennines ; and while the sluggish river is forming inland plains with its mud, the rapid torrent is carrying its burden forward to the bottom of the ocean.

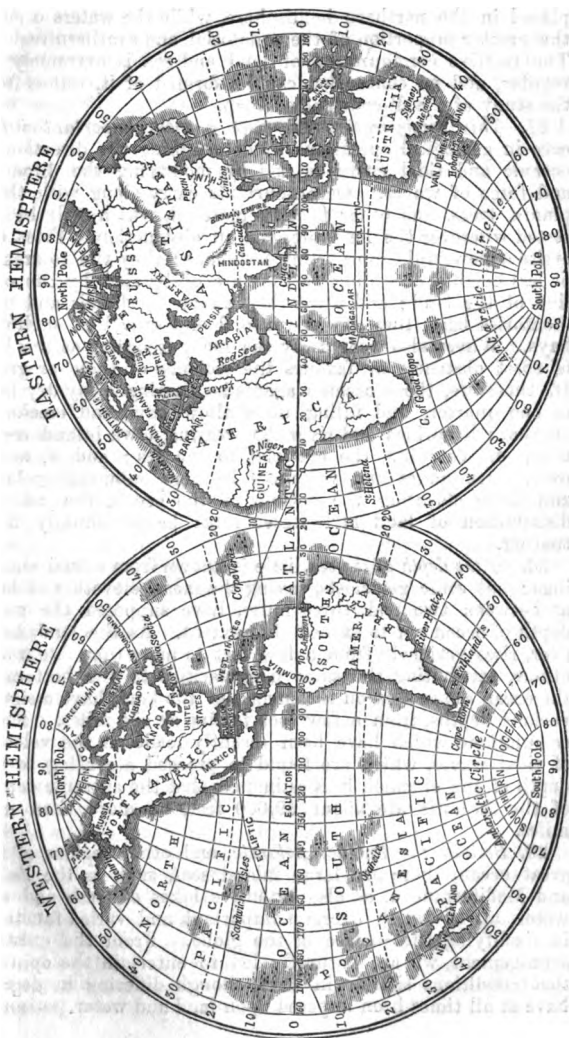
24. *The surface outline of the earth is so irregular that even physical geography, with all the facilities afforded by modern intercourse, has yet presented us with a very general description; and before we can estimate the full force of this configuration as a geological agent, we must know more of the relative elevations and depressions of the land, and the nature of the rocky substances so elevated and depressed. Of the surface configuration of the world in its earlier ages, we have no positive knowledge; but we are certain that whatever it might be, it would materially influence the changes then going forward, just as the same cause is operating at the present moment.*

DISTRIBUTION OF LAND AND WATER.

25. *THE DISTRIBUTION OF LAND AND WATER, upon which so many geological phenomena depend, is influenced by this principle alone; namely, that so long as the same quantity of water remains on the globe, a fixed amount of space will be required to contain it. If the difference between the elevations and depressions of the solid crust be small—in other words, if the hollows in which lakes and seas are spread out be shallow—their waters must extend over a greater space; and if these hollows be deep, the waters will occupy less extensive areas. The operation of this principle the student should bear in mind; for if, in the earlier ages of the world, the elevation of the land was less general, the waters would occupy larger spaces, and this more extended area of shallow water would act in various ways. It would render the climate more genial and uniform, and extending a greater surface to the evaporating power of the sun, rains and atmospheric moisture would be more prevalent. These, again, would operate on the amount and kind of animal and vegetable life on dry land; while the shallow waters themselves would be more productive of life, it being a well-known fact, that shell-fishes and aquatic plants flourish only at limited depths around the shores. Of the distribution of land and water at any former period of the world, we can only infer from the appearances which the surface and rocky strata present; but of the present distribution, we have pretty accurate information, with the exception of those regions surrounding either pole.*

26. *The proportion of dry land to water, as at present existing, is about one to three; that is, three-fourths of the whole surface of the globe may be assigned to water. The dry land presents itself in islands and continents variously situated; but the student has only to cast his eye over a map of the world, to observe that the greater portion is*

MAP OF THE WORLD.



placed in the northern hemisphere, while the waters occupy the greater proportion of the equatorial and southern regions. The relative configuration of land and sea is extremely irregular, and no conception can be formed of it, unless from the study of a well-constructed map.

27. *This configuration exercises a most important influence* in geological operations by determining the direction of oceanic and tidal currents, and by modifying the direction and force of waves. Ocean-currents carry along with them plants, trees, and other floating material, which will be arrested wherever the land presents an obstruction. Tides exercise a powerful transporting influence: they rise to greater or less heights, according as they are obstructed by the outline of the land; and while they sweep headlands and promontories bare, they lay down sand and gravel in sheltered bays. Waves also wear away the land, according as the line of coast obstructs or favours the violence of their progress. If, therefore, these oceanic agents be wearing away dry land in one quarter, and filling up shallow bays and creeks in another; if springs and rivers be wearing down inland countries, and carrying the material to the sea; and if, moreover, earthquakes and volcanoes be here submerging land, and there elevating the bottom of the ocean, the relative distribution of land and water must be continually fluctuating.

28. *Of the depth of the sea* little is known from actual soundings; but some geologists, taking the mean elevation of land at between two and three miles, have supposed the mean depth of ocean not to exceed that extent. As the land, however, rises variously from a few feet to more than five miles, others, attributing the same irregularities to the bottom of the ocean as are seen on the surface of the land, have assigned various depths, from a few feet to five or six miles. From calculations which have been recently made on the velocity of tidal waves, which are found to proceed according to the depth of the channel, it is estimated that the extreme depths of the Atlantic are about 50,000 feet, or more than nine miles.

29. *Besides the Pacific, Atlantic, and other regions of the great ocean,* there are large inland seas, such as the Baltic and Mediterranean, as also extensive lakes of fresh and salt water, all of which exercise important and varied functions in modifying the surface of the globe. From the existing arrangement, we are naturally led to entertain the opinion, that conditions similar in kind, though differing in degree, have at all times been imposed upon land and water.

CONSTITUTION OF THE OCEAN.

30. OF THE CONSTITUTION OF THE OCEAN chemical research affords us pretty accurate data. Water, whether fresh or salt, may contain impurities—such as clay, sand, gravel, animal and vegetable matter; but if left at rest, these by their own weight soon fall to the bottom. Such substances are said to be *mechanically* suspended; and, when deposited at the bottom, they form *sediment*. Besides impurities of this description, water may contain matter which will not fall down, and which is said to be held in *chemical solution*. Sea water of the Atlantic, according to Dr Marcet, contains 4 3-10th grains of saline matter in every hundredth; while, according to Dr Murray, the water of the German Ocean contains only 3 3-100th grains. This saline matter consists chiefly of muriate of soda (common salt), sulphate of soda, muriate of lime, and muriate of magnesia. It has been also ascertained that the southern ocean contains more salt than the northern; that small inland seas, though communicating with the ocean, are less salt than the ocean; that the Mediterranean contains a greater proportion of saline matter than the Atlantic; and though the saltness of the sea be pretty uniform at great depths, still, at the surface, owing to the admixture of rain, river, and iceberg water, it is not quite so salt.

31. *A knowledge of the constitution of the ocean* is necessary to the explanation of numerous facts in geology. The saline constituents must influence more or less all chemical changes, rock deposits, and animal and vegetable life, which take place in the ocean. From these constituents shell-fish and coral animals derive the matter of which shell-beds and coral-reefs are constructed; and by this same constitution, marine animals and plants are made to assume a character which distinguishes them from the inhabitants of fresh waters.

32. *The pressure of the sea* (which depends on its depth) also exerts an important influence, as what takes place near the surface would be impossible at greater depths. There, animal and vegetable life, as known to us, cannot exist; sand and mud, which remain loose near the shore, would become much consolidated if subjected to this pressure; and, according to the experiments of Sir James Hall, even limestone could be fused without the loss of its carbonic acid. Other results, depending upon the present constitution of the ocean, might be pointed out; but enough, we trust, has been stated to impress the student with a conviction of its geological importance.

THE ATMOSPHERE.

33. **THE ATMOSPHERE**, which everywhere surrounds the globe, is either of itself the immediate cause of numerous terrestrial changes, or it is the medium through which they are effected. The air is a gaseous fluid, produced by the combination of 79 parts of nitrogen with 21 of oxygen, every 100 such parts containing a small portion of carbonic acid and other extraneous impurities. It is indispensable to the life of plants and animals, and an alteration of its constitution would completely change the relations of animated nature; for, while a greater proportion of carbonic acid would be highly favourable to vegetation, it would be utterly destructive to animals. The proportion of nitrogen and oxygen in the atmosphere is at present nearly as 4 to 1; change this, and 5 of oxygen with 1 of nitrogen forms a compound (nitric acid, or aquafortis) so corrosive, that even the metals are dissolved by it. The air is an elastic or compressible medium; and, consequently, the lower strata near the earth will be compressed by the weight of those above them, and thus the air will become rarer as we ascend. From measuring the rate at which this rarity takes place, it has been calculated that at the height of forty-five miles the atmosphere would become so rare as to be inappreciable. Forty-five miles has, therefore, been assumed as the limit of the atmosphere.

34. *This aerial medium is the laboratory in which numerous operations are effected.* Vapours, rains, snows, clouds, winds, and electricity, are among the most apparent of these, and are continually influencing the earth's surface; either mechanically, as by rains and winds; chemically, as by carbonic acid; electrically, as by electrical phenomena during thunder; or vitally, as in the support of plants and animals. So far as we can learn from human history, the constitution of the atmosphere has continued without sensible change; but of its primeval constitution we know nothing, but are left to infer of its conditions from the character of the plants and animals imbedded in the rocky strata. At present, atmospheric agency is exerted in a thousand ways, and analogy warrants us to conclude that such has always been the case; this agency being the same in kind, though perhaps differing in degree.

PLANETARY RELATIONS.

35. **THE PLANETARY RELATIONS OF THE GLOBE** exert a permanent, and, it may be, sometimes a temporary and peculiar

influence on the changes which have been effected, or are now going forward, on its surface. From the sun it derives light and heat, those agencies so indispensable to animal and vegetable existence; on its relation to the sun and moon depend those important tidal influences already adverted to; while to the same relation it owes its daily and annual revolutions, with all their attendant results. A permanent increase or diminution of the sun's heat would change the whole vegetable and animal economy; the approach of a comet might derange the present order of the globe's rotations; and a slight shifting of the earth's axis, so as to displace the present planetary positions of its poles and equator, would so alter the distribution of plants and animals, would so derange its surface configuration, and change the distribution of land and sea, that the face of nature would then present an entirely different picture. So far as history or the calculations of astronomy over a space of 3000 years will permit us to infer, no such revolutions have taken place; nor do the tides, the sun's heat or light, seem to have been in the least affected. But while this is true, it does not prevent the possibility of such changes; and certain geological appearances present themselves in the earth's crust, which cannot be accounted for unless by the supposition of such revolutions.

36. *The daily and annual rotations of the earth, the sun's light and heat, the ebb and flow of the tides, &c. are permanent occurrences, dependant on the planetary relations of the globe; catastrophes, such as would arise from the contact of a comet, a change in the position of the earth's axis, or the like, would be temporary and peculiar.*

EXPLANATORY NOTE.

ELEVATIONS AND DEPRESSIONS.—These are terms applied to the risings and fallings of the surface of the earth—from the slightest undulation to the highest mountain, and from the gentlest hollow to the greatest depth of ocean. The greatest heights with which we are acquainted are those of the Himmaleh range in Asia, the Dhawalagiri Peak being 28,077 feet, and the Jewahir 25,747. The Andes, in South America, are the next in order, the Nevado di Sorato being 25,250 feet, and Illimani 24,450. In Europe, the Alps rise (in Mont Blanc) to 15,668 feet, the Pyrenees to 11,283; and in Africa, Geesh, in Abyssinia, is 15,000, and the Peak of Teyde (Teneriffe) gives 12,180. As some parts of the dry land are above the level of the sea, so also some portions are beneath—such as the central regions of Asia around the Caspian and the Aral seas, where the surface has been ascertained to be from 80 to 100 feet actually lower than the level of the ocean. But the greatest depressions in the solid crust are those occupied by the sea, where actual soundings have reached depths of nearly a thousand

fathoms ; and to which other calculations have assigned a depth of no less than nine miles.

AVALANCHES (French, *lavanches*, *avalanches*)—are accumulations of snow, or of snow and ice, which descend from lofty mountains, like the Alps, into the valleys beneath. They originate in the higher regions of mountains, and begin to descend when the gravity of the mass becomes too great for the slope on which it rests, or when fresh weather destroys its adherence to the surface. Avalanches are generally distinguished as *drift*, *rolling*, *sliding*, and *glacier* or *ice avalanches*. Drift are those caused by the action of the wind on the snow while loose and powdery ; rolling, when a detached piece of snow begins to roll down the steep—it licks up the snow over which it passes, and thus acquires bulk and force as it descends ; sliding, when the mass loses its adherence to the surface, and descends, carrying everything before it which is unable to resist its pressure ; and glacier or ice, when pieces of frozen snow and ice are loosened by the heat of summer, and precipitated into the plains below.

ICEBERG (German *eis*, ice, and *berg*, mountain)—the name given to the masses of ice resembling mountains, often found floating in the polar seas. They are sometimes formed in the sea itself by the accumulation of ice and snow ; at other times they seem to be glaciers which have been piling up on a precipitous shore, till broken off and launched into the ocean by their own weight. Masses of this kind have been found in Baffin's Bay two miles long and half a mile in breadth, rising from 40 to 200 feet above the water, and loaded with beds of earth, gravel, and rocks. Some idea of the size of these icebergs may be formed from the fact, that the mass of ice below the level of the water is about eight times greater than that above. As they float towards warmer regions, they gradually dissolve, dropping their burden of rock debris, and thus strewing the bottom of the ocean with clay, gravel, and boulder stones, some of which are many tons in weight.

PROPORTION OF LAND AND SEA.—The proportion of land to sea is, accurately, as 266 to 734. If, therefore, the whole superficies of the globe be taken at 196,816,658 square miles, it follows that the dry land occupies 52,353,231 square miles, and the ocean an area of 144,463,427 square miles.

PRESSURE OF THE ATMOSPHERE.—If the density of air at the surface of the earth be represented by one, at seven miles above the earth it will be 1-4th, at fourteen miles 1-16th, at twenty-one miles it will be 1-64th, and so on. This property of air would lead to the idea of an indefinite extension of the atmosphere, but there is evidently an appreciable limit to this ; and hence, by calculations relative to the progress of the sun's light, and other astronomical phenomena, forty-five miles has been fixed as the altitude of the atmosphere. Air is ponderable—100 cubic inches at the temperature of 60 degrees weighing 30½ grains. A perpendicular column of the whole atmosphere is balanced by one of mercury rising to 30 inches ; hence the atmosphere presses on every cubic inch of surface with a weight equal to 16 pounds.

PRESSURE OF THE OCEAN.—Water being slightly compressible, it follows, as in the atmosphere, that water at great depths in the ocean will be denser than at the surface. According to calculations by Oersted, water at the depth of 1000 feet is compressed 1-340th part of its own bulk.

CAUSES MODIFYING THE STRUCTURE AND CONDITIONS OF THE GLOBE.

37. Had the general structure and conditions of the globe, as described in the foregoing section, been subjected to no modifying causes, they would have remained unchanged from the beginning of time, and the earth would have presented now the same appearance as at any former period. But these very conditions are themselves the causes of change, for they mutually act upon each other, and give rise to innumerable agents which have continued through all time to modify the face of nature. Thus, for example, the planetary relations of the earth enable it to derive heat from the sun; this heat vaporises the water of the ocean, the vapour produces rains, these rains form springs and rivers, the rivers wear down the land, and thus change the surface configuration; the matter borne down by the rivers forms new land along the sea-shore, altering the distribution of land and water; and this distribution of land and water materially affects the kind and distribution of plants and animals. This is a simple instance of the changes produced by the action and reaction which takes place among the general conditions of the globe; and the student would do well, at this stage of his progress, to familiarise himself with such trains of cause and effect, as it is only by the ready application of similar reasoning that he will be able to comprehend many of the phenomena hereafter described.

38. *The modifying causes* produced by the mutual influence of the general conditions already considered are exceedingly numerous and varied. At present, it is necessary to notice only such as seem to account for the principal facts connected with the solid materials which form the crust of the globe, and the order and manner of their arrangement. These causes, or agents, may be divided into four great classes; namely, ATMOSPHERIC, AQUEOUS, IGNEOUS, and ORGANIC; and their modes of action may be either *mechanical*, *chemical*, *electrical*, or *vital*.

ATMOSPHERIC AGENCIES.

39. ATMOSPHERIC AGENTS act either mechanically or chemically: the action of wind in drifting loose sand is mechanical, the action of the air in *weathering* the surface of rocks is chemical. The atmosphere may either act directly, as in

the case of winds, or indirectly, as in the production of waves, the effects of which on the sea-coast are often destructive and extensive. The changes produced on the earth's crust by atmospheric agency are sometimes slow and gradual, such as in the crumbling down of rocks; or immediate, as in the uprooting of forests by tempests, and the covering of green valleys by barren sand-drift. The air, or atmosphere, is one of the most important elements, and is more or less connected with every operation in nature. By it the sun's light and heat are equally diffused; it is indispensable to the existence of plants and animals; and it is the great laboratory in which the waters of the ocean are purified and distributed over the face of the globe. These may be said to be universal functions of the atmosphere. It also acts peculiarly, and over limited extent, as in the production of winds, frost, heat, electricity, and gaseous admixtures.

40. *Winds* are aerial currents. When the air of one region becomes heated or rarefied, the colder and heavier air of the surrounding regions rushes in to restore the balance, and thus atmospheric currents are produced. These currents are extremely unstable, blowing without regard to time or direction, and modified and obstructed in a thousand ways by hills, valleys, and other surface irregularities. They are equally unstable in their velocity, varying from the gentlest breeze to the fiercest hurricane which overturns cities and uproots forests. But though characterised by these irregularities over the greater portion of the globe, there are regions over which they pass with wonderful steadiness for months together. The trade-winds which take place within the tropics possess this character, and blow from east to west with little variation of direction or force. The monsoons, which are connected with the trade-winds, are also pretty regular; and in most countries an east, a south, or a west wind, is found to prevail over other directions, and that at particular periods of the year. Of the phenomena of winds in the earlier eras of the world we have no knowledge; but we are warranted to conclude, that since the elevation of dry land, and the distribution of land and water, they have been analogons to what is now in daily occurrence.

41. *Wind acts on all loose material*, bearing it from exposed to sheltered places. Sand, gravel, and loose shells are most frequently shifted by its force, and blown into hillocks, or scooped out into hollows, without order or regularity. All those extensive tracts of sand found along the sea-coast—known in Scotland as *links*, and as *downs* in England—owe their surface formation to wind. The sand collected in bays

and creeks by the waves and tides of the ocean, is no sooner left dry by the tide, and exposed to the sun, than it becomes light, and easily acted upon by the wind, which raises it into knolls and ridges beyond the influence of the returning tide. By and by a scanty herbage gathers over the sand, and thus, in course of ages, extensive downs are formed. In a similar manner the wind acts upon the sandy deserts of Arabia and Egypt, continually shifting their surface; and if it sets in from any prevailing direction, these sands are carried forward, year after year, burying trees, fields, and villages, and thus converting fertile districts into barren wastes. When a river enters the sea through a sandy district, it has a tendency frequently to shift its channel; and this tendency is greatly increased by winds damming up the current with drifted sand. Volcanoes occasionally discharge showers of dust and ashes, which, during high winds, are carried over many leagues of surface, or borne out to the ocean. During calm weather volcanic dust and ashes would fall in the neighbourhood of the crater; during high winds they may be deposited at vast distances from their original sources. Such examples as the above are the ordinary actions of wind: the uprooting of forests, the destruction of cities, and the like, are extraordinary, and are caused by whirlwinds and hurricanes.

42. *Frost exercises a slow but permanent influence in modifying the surface configuration of the globe.* When the heat of the surrounding atmosphere falls below 32 degrees of the thermometer, water begins to freeze, and in this state expands. During winter or moist weather, water enters between the particles of all rocky matter at the surface of the earth, and also into the larger fissures; and the expansion of this water by frost separates these particles, and leaves them to fall asunder when the ice is dissolved. This takes place more or less every winter; and there is not a cliff or hill side but bears evidence of this kind of action. The effects of frost in crumbling down rocky material has been long observed: the farmer takes advantage of it to pulverise his soil; and in some districts slate and flagstone are split into thin laminæ by being exposed to the frost.

43. *Of the amount of change produced by frost,* it would be difficult to form an estimate; but, taking it over a lapse of ages, there can be little doubt that it has been an important agent. In mountain regions, such as the Alps, its effects are strikingly apparent in the formation of avalanches; and in northern latitudes the iceberg is one of its familiar productions. The action of frost in crumbling down a rocky surface seems slow and insignificant, but when we look

upon the avalanche carrying rocks, gravel, trees, and houses before it, and burying them in one common ruin; when we look upon the iceberg laden with huge stones, and dropping them into the ocean as it dissolves, we are more impressed with its importance, and are enabled to account for certain geological appearances which no other agency could have produced. (See note, page 24.)

44. *Solar heat and light* may, without much impropriety, be classed as atmospheric agents, as the atmosphere is the medium through which they act, and by which they are modified. Water conducts heat faster than air, and air, at the surface of the earth, faster than highly rarefied air at great heights; hence different conditions of the atmosphere may have hitherto conducted more heat to the earth's surface. The quantity of light which reaches the earth depends upon the serenity of the atmosphere, and the height of the sun above the horizon; hence, also, a different condition of atmosphere would produce a different amount of light.

45. *Heat and light are indispensable to vegetable and animal existence*; and the kind and number of plants and animals depend, in a great measure, upon the degree and uniformity of their influence. Heat converts water into vapour, and vapour forms dews, rains, &c. The amount of vapour, and consequently the amount of rain, will depend upon the degree of heat; and hence the heavy periodical rains of the tropics. A higher degree of heat all over the earth would greatly increase the amount of rains, these rains would form more gigantic rivers, and geological effects of corresponding magnitude would follow.

46. *Of the amount of solar heat received by the earth* at any former period, we are left to infer from the kind of plants and animals which are found imbedded in the rocky strata; a scantiness and peculiar character of these remains indicating a temperature analogous to that of the polar regions, and numerical amount and external form indicating a climate similar to that of the tropics.

47. *Electricity is also ranked among atmospheric agents*, though electric, galvanic, and magnetic influences may be going on in the crust of the globe totally independent of the atmosphere. The effects of these subtle forces are not easily calculated; and what connexion they may have with earthquakes, with the formation of metallic veins, and similar phenomena, geology has not been able to determine. We know that the hardest and most untractable substances in nature can be artificially dissolved and reconstructed by the aid of electricity; this force sometimes acting slowly and

insensibly, and other times with rapidity and violence. We know, also, that what the chemist has not been able to effect by the most powerful charges of electricity, has been accomplished by the slow and almost insensible effects of the same agent. What takes place in the laboratory of the chemist may be daily occurring in nature. We occasionally perceive the violent effects of electricity during a thunder-storm; but these may be trifling in comparison with what is hourly, but insensibly, taking place among the materials which compose the crust of the earth. We often hear of the disasters of a tropical thunder-storm, where the electric fluid demolishes houses, rends trees, sets fire to forests, or shivers rocks; but these consequences, though startling, produce no extensive terrestrial changes; so that it is to the slow and unseen agency of this power in producing peculiar transformations of metallic and other matter, that its importance in geological reasoning is mainly to be ascribed.

48. *The gaseous constitution of the atmosphere* acts chemically, not mechanically. In its ordinary state, as we have already seen, every 100 parts are composed of 79 nitrogen and 21 oxygen, with a small proportion of carbonic acid, amounting to little more than one part in a thousand. This constitution is essential to animal and vegetable life; hence the student can readily conceive how any extensive alteration of this mixture would operate. Carbonic acid gas is given off by some springs, by volcanic fissures, and by similar sources both in the sea and on dry land. This gas is destructive to life; and consequently shoals of fishes, or herds of animals, coming in contact with any extensive exhalation of it, would be instantly suffocated. Other gaseous fumes are also destructive to life; and bearing these facts in mind, we may be enabled to account for peculiar accumulations of animal remains in certain situations in the rocky strata.

49. *Rocks exposed to the atmosphere* absorb air and moisture, and the action of this air and moisture *weathers*, or dissolves the union of the outer particles. These outer particles fall off by the force of gravity; another set of particles are exposed to the same wasting influence; and thus, year after year, every rock and mountain is losing more or less of its material.

50. *Oxygen and carbonic acid are the principal agents* in this operation. All metallic substances are acted on by oxygen; it tarnishes their surface, gradually eats into their mass, and in time converts them into a loose powdery substance. Iron affords a familiar illustration of this fact: however well polished, if exposed to air and damp, it begins to rust, film

after film, till the whole is in time converted into a reddish powder, called rust, or oxide of iron. All the igneous rocks, and most of the aqueous, contain iron disseminated in minute particles through their mass, and are therefore liable to be acted upon by oxygen. It is this oxide of iron which gives the reddish colour to many rocks and mineral waters.

51. *The formation of many soils is owing to this pulverising power of the atmosphere*; and as their loose matter is washed down by rains and rivers, a new supply is formed by further disintegration of the rocks beneath. We have no means of ascertaining the amount of change produced by the chemical constitution of the atmosphere; but this we know, that it must have exerted itself through all time most powerfully in warm damp climates, and least where the air was clear and arid. Soft clays and shales are easily weathered down; so, also, are all kinds of volcanic rocks; and even granite has been known to be pulverised to the depth of three inches in six years.

52. *The atmospheric agents chiefly instrumental in modifying the crust of the globe*, all, more or less, exert a degrading or wasting influence; that is, a tendency to wear down the surface to a lower level. Wind occasionally presents an exception to this statement, and tends to raise the surface; as in the formation of downs and sand-hills of considerable elevation, like those of Barry at the mouth of the Tay. Atmospheric forces act either mechanically, chemically, or vitally; are universal in their operations, with perhaps the exception of frost in the tropics; and must have exercised an important influence on the geological conditions of the earth from the beginning of time.

EXPLANATORY NOTE.

ATMOSPHERIC, AQUEOUS, IGNEOUS, AND ORGANIC.—The student should make himself perfectly familiar with the application of these terms. Wind, for example, is a purely atmospheric agent; springs, rivers, and waves, are aqueous agents; volcanoes are igneous agents, and, geologically speaking, the term is chiefly applied to forces or results depending upon the internal heat of the earth; and organic agents are such as arise from animal or vegetable life. Organic (Greek, *organon*, an instrument or machine) is applied to vegetable or animal structures, as being made up of parts nicely adapted to each other. All matter resulting from the growth or decay of plants and animals is said to be organic.

MECHANICAL, CHEMICAL, ELECTRICAL, AND VITAL.—A piece of chalk may be brayed to powder by pounding it in a mortar; it may also be reduced to powder by dissolving it in sulphuric acid; in the former instance the action is *mechanical*, in the latter *chemical*. In whatever

manner electricity acts, the action is said to be *electrical*; the recombination of blue vitriol (sulphate of copper) into metallic copper, as is done in electrotyping, is an example of this kind of action. *Vital* is applied to any sort of action depending on life, whether in animals or vegetables.

WINDS.—Besides the *trade-winds*, blowing within the 25th degree of latitude on either side the equator, there are the *monsoons*, which are merely the trade-winds diverted north or south by the land that lies within these parallels; the *simoom*, a burning pestilential blast, which rushes with fury over the sandy deserts of Arabia; the *harmattan*, a cold dry wind, frequent in Africa and in Eastern countries; the *sirocco*, a hot, moist, and relaxing wind, which visits Italy from the opposite shores of the Mediterranean; the *bise*, a cold frosty wind, which descends from snow-covered mountains, such as the Alps; and *whirlwinds* and *tornados*, that are common to all countries, but most destructive in warm regions.

FREEZING.—Water, at the temperature of 40 degrees, may be said to be stationary as to bulk; but if the temperature be reduced, it begins to expand, till, at 32 degrees, it freezes, and is converted into solid ice, in which state it is 1-14th larger than its original volume. On the other hand, if the temperature be increased, the water is gradually converted into vapour, till, at 212 degrees, it boils, and is rapidly expanded into steam, in which state it is 1700 times its original bulk. Steam can be still further expanded, till almost no known force is able to resist it.

PULVERISE (Lat., *pulvis*, dust)—to reduce to dust or powder. Soil, which is reduced to small particles by the action of frost, is said to be pulverised. So also of rocks.

DISINTEGRATE (Lat., *dis*, asunder, *integer*, whole)—to break asunder any whole or solid matter. The *disintegration* of rocks is caused by the slow action of the atmosphere or by frosts, &c.

DEGRADING, DEGRADATION (Lat., *de*, down, *gradus*, a step)—to take down from one level to another. The degradation of hills and cliffs is caused by rains and rivers; hence water is said to degrade, or to exercise a degrading influence on the land. Degradation and elevation of land are opposite terms.

DENUDATION (Lat., *denudo*, I lay bare)—a term sometimes employed as synonymous with degradation, but inaccurately so. For example, *disintegration* strictly applies to that action by which the materials of solid rocks are loosened or separated from each other; *degradation* to the carrying of these materials from a higher to a lower level; and *denudation* to the removal of superficial matter by water, so as to lay bare the inferior strata.

AQUEOUS AGENCIES.

53. **AQUEOUS AGENTS**, or those arising from the power and force of water, are perhaps not so universal or so complex in their operations as atmospheric; but they are more powerful, and consequently exert a more obvious influence in modifying the crust of the globe. Their mode of action is either mechanical or chemical: mechanical, as when a river wears away its banks, and carries the material to the sea; and chemical, when, from gaseous admixture,

water is enabled to dissolve certain rocks and metals. The action of water is sometimes slow and gradual, as in the wearing down of rocks by rain ; or rapid and violent, as in the case of river-floods and sea-storms. The effects of rain upon a cliff may not amount to one inch in a hundred years, while hundreds of acres of alluvial land may be swept to the ocean by one river-flood. Water operates variously : sometimes by itself, as in rivers ; sometimes in union with the atmosphere, as during land and sea-storms. Its power as a geological agent is most obvious in the case of rains, springs, rivers, lakes, waves, currents, and tides ; and the results of these agents are distinguished as *meteoric, fluvial, lacustrine*, or *oceanic*.

54. *Rain, hail, snow, and all atmospheric vapours, exercise a degrading influence on the earth's surface.* By entering the pores and fissures of rocks, they soften and gradually dissolve their surface, and thus materially assist the operations of frosts, winds, &c. Rain, accompanied by high winds, acts with greater force ; snow, from accumulating during frost, and suddenly dissolving during fresh weather, sometimes occasions violent floods and inundations. Floods arising from the melting of snow are generally very destructive, for, during the season when they occur, the surface is soft and loose, and much more liable to be carried away. Rain and other vapours are indispensable to the growth of vegetables, and when accompanied with sufficient warmth, a luxuriant and gigantic vegetation, like that of the tropics, is the result. The amount of rain which falls on the earth's surface is exceedingly varied, ranging from 20 or 30 inches to several feet per annum. In tropical regions, rains are periodical ; that is, fall for weeks together at certain seasons. This gives rise to inundations ; hence the peculiar phenomena attending the floodings of such rivers as the Nile, Ganges, &c.

55. *Of the quantity of rain which fell during past periods of the world* we have no positive knowledge ; but if we are able to discover evidence of a higher temperature, we are warranted in concluding that the quantity of rain was much greater. A greater fall of rain would produce larger rivers, and larger rivers would carry down a greater quantity of silt and debris ; this would form more extensive plains and deltas ; and these, again, would sustain a more gigantic race of plants and animals. From this example, the student will readily perceive the connection and influence of these allied causes. Rain water generally contains carbonic acid, ammonia, and other substances ; and, consequently, acts chemically as well as mechanically.

56. *Springs are discharges of water from the crust of the*

earth either by rents, fissures, or other openings in the surface. The water which falls in rain, snow, &c. partly runs off, and partly sinks into the crust, where it collects in vast quantities, and ultimately finds its way again to the surface by springs. Springs issuing from strata at great depths are said to be *deep-seated*; those from clay or gravel are *shallow*. Some only flow during or shortly after rains, and are said to be *temporary*; some flow always, and are *perennial*; while others flow and ebb, and are said to be *intermittent*.

57. *The characters in which geologists have principally to consider springs* are cold, thermal, and mineral. Cold springs have a mechanical action when they cut out channels for themselves; and they act chemically when, for example, they contain carbonic acid, and dissolve portions of the rocks through which they pass. All petrifying springs—that is, such as convert wood and bones into stony matter—act chemically. Thermal, or hot springs, occur in numerous parts of the world (England, Iceland, Germany, Switzerland, Italy, Hindostan, &c.), and also act mechanically and chemically, but with much greater chemical force than cold springs. Mineral springs may be either cold or hot, and take their name from the circumstance of their waters holding some mineral or earthy substance in solution.

58. *Mineral springs, geologically speaking, are by far the most important*, as, from their composition, they indicate the kind of rocks through which they pass, while they more or less influence all deposits or waters into which they flow. Thus, some contain iron, and are said to be ferruginous, or chalybeate; some copper (cupriferous), some lime (calcareous), some salt (saline), while others give off sulphureous vapours; and so on with almost every known mineral. Those issuing from strata containing iron or lime are more or less impregnated with these substances; and when they arrive at the surface of the earth, and their waters become exposed to the air, the ferruginous or limy matter is deposited along their courses, or is carried down to the nearest river or lake. If layers of mud, sand, or gravel be forming in such a lake, these layers will be impregnated with the matter of the springs; hence geologists speak of ferruginous, calcareous, or saliferous strata. Mineral springs may therefore be said to exert a twofold influence: first, by dissolving and carrying away matter from the strata beneath; and, second, by adding that matter to the strata which are now being formed on the surface. The student will thus perceive the manner in which springs act in modifying the crust of the earth; and in proportion to their size, the softness of the strata through which

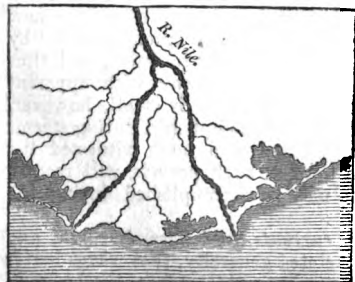
they passed, and the degree of heat they had acquired, so must the extent of their influence have been at any former period.

59. *Rivers are the most important aqueous agents* employed in modifying the surface of the globe. Springs, as they issue into open day, naturally seek a lower level; and numbers of them meeting in one channel, form streams, which again join in some still lower valley, where their union produces rivers of various sizes. Rivers may be said to be a species of natural drainage, by which the superabundant moisture which falls on the land is again returned to the sea. They are of all dimensions; in breadth from a few feet to several miles, so shallow that a boy might wade them, or so deep as to float the largest ships, and ranging in length of course from fifty or sixty miles to as many hundreds.

60. *The geological action of rivers is twofold*; first, by wearing down the land through which they pass, and then by carrying down the material to lakes and seas. Both their degrading and transporting force depends upon their velocity. For example, it has been calculated that a force of 3 inches per second will tear up fine clay, 6 inches will lift fine sand, 8 inches sand as coarse as linseed, and 12 inches fine gravel; while it requires a velocity of 24 inches per second to roll along rounded pebbles an inch in diameter, and 36 inches per second to sweep angular stones of the size of a hen's egg. Rivers, during floods, often acquire a much greater velocity than this, and stones of considerable weight are then borne down by their currents. The degrading power of running-water depends also upon the kind of material through which it flows; loose soil, clay, and sandstone being easily worn down, while granite or basalt will suffer little loss for centuries. The mere flowing of pure water would exert little influence on hard rocks; but all rivers carry down sand and gravel; and these, by rubbing and striking against the sides and bottoms of the channel, assist in scooping out those channels which everywhere present themselves. The Nerbuddah, a river of India, has scooped out a channel in basaltic rock 100 feet deep. Messrs Sedgwick and Murchison give an account of gorges scooped out in beds of the rock called conglomerate, in the valleys of the Eastern Alps, 600 or 700 feet deep. A stream of lava, which was vomited from *Ætna* in 1603, happened to flow across the channel of the river Simeto. Since that time the stream has cut a passage through the compact rock to the depth of between 40 and 50 feet, and to the breadth of between 50 and several hundred feet. The cataract of Niagara, in North America, has receded nearly 50 yards during the last forty years. Below the Falls, the

river flows in a channel upwards of 150 feet deep and 160 yards wide, for a distance of seven miles; and this channel has evidently been produced by the action of the river. Such effects as the above are produced by the general or ordinary action of water; but when rivers are swollen by heavy rains, by the sudden melting of snow, and the like, then they act with extraordinary violence. In these cases they overflow their banks, rush with a velocity of 20 or 30 feet per second, tear up the soil, and sweep before them trees, animals, houses, and bridges. The water of all rivers which exert a degrading influence is more or less turbid, and an idea of their power may be formed by observing this fact.

61. *The matter which rivers carry down* is either deposited along their banks, in lakes, or in the ocean. If they flow sluggishly along a flat valley, the mud and sand which their waters contain gradually falls to the bottom, and there rests as sediment. This sedimentary matter forms what is called *alluvial* land, and most of the flat and fertile valleys in the world have been so produced. Again, when a lake occurs in the course of rivers, the sediment is there collected, and the water issues from the lake as if it had been filtered. In progress of time, lakes are filled or *silted* up with this sediment, and their basins appear first as marshes, and latterly as alluvial land. But whatever quantity of matter may be deposited in valleys or lakes, the greatest amount will always be carried down to the ocean, and deposited at the mouth of the river or along the shores. The heaviest material, such as gravel, will fall down first, then the lighter sand, and ultimately the finest mud. The mud of the Ganges discolours the Bay of Bengal to a distance of 60 miles from its mouth; and according to Captain Sabine, the muddy waters of the Amazon may be distinguished 300 miles from the shore.



62. *The consequence of this continual seaward-carriage of sedimentary matter* is, that at the mouths of most rivers there are alluvial formations, known by the name of *deltas*; such as those of the Nile, the Ganges, the Niger, &c. They take their name from their resemblance in shape to the Greek letter Δ (delta); and fre-

quently extend over vast surfaces—that of the Ganges being about 200 miles in one direction by 220 in another. They consist of alternate layers of sand, gravel, or mud, according to the kind of material the river carries down. The foregoing cut represents the Delta of the Nile, which is generally regarded as the type of all similar deposits.

63. *The geological results effected by the agency of running water* are ceaseless and universal. Rivers are gradually wearing down the hills and higher lands, and as gradually silting up lakes and low tracts of valley land. They lay down beds of gravel, sand, or mud; and these beds, again, enclose trees, plants, the bones and shells of animals, in greater or less abundance. As rivers now act, so must they have always acted, and to this kind of agency must we ascribe the formation of many of the rocks (with their fossils) which now form the crust of the earth both at great depths and at distances now far removed from the sea. We have no actual knowledge of the rivers of the ancient world; but, judging from the extent of sedimentary rocks, they must have been much more gigantic than most of those now existing.

64. *Waves, currents, and tides, are also powerful geological agents.* Waves are continually in action; and according to their violence, and the materials composing the sea-coast, so is the amount of change produced. Cliffs of sandstone, chalk, clay, or other soft rock, are, year after year, undermined by their force; masses fall down, are soon ground to pieces, and swept off by every tide; new underminings take place, new masses fall down, and thus thousands of acres of land have been reduced to a level with the sea. What the waves batter down, the tides and currents transport to sheltered bays and creeks along the shore; so that, while in one quarter the sea is making encroachments on the land, in another it is accumulating sand and gravel to form new land. The power of waves and currents is much increased by the fact, that rocks are more easily moved in water, and thus gravel beaches are piled up or swept away with apparent facility. The ordinary action of the sea is small, however, compared with what is sometimes accomplished during storms and high inundations; and those who have witnessed the effects of a few successive tides at such periods, will readily form an estimate of what may be accomplished during the lapse of ages.

65. *The action of waves, currents, and tides, is varied and complicated;* but it may be stated generally, that waves batter down the sea-cliffs, or raise up loose matter from the bottom;

that tidal currents convey the disintegrated matter to more sheltered bays and creeks; and that oceanic currents convey floating material, such as drift-wood, plants, and dead animals, from one part of the ocean to another. Tides rise and ebb from 4 to 40 feet; they enter into certain rivers for many miles; and thus a mingling of fresh water and marine deposits take place. As at present, so in ages past; and by diligently studying the effects produced by waves and tides, the student will be enabled to account for many appearances which the sedimentary rocks present.

EXPLANATORY NOTE.

THE ACTION OF WATER is said to be *meteoric* when it acts through the atmosphere; *fluvial* (*fluvius*, a river) when it acts by running streams or rivers; *lacustrine* (*lacus*, a lake), by pools or lakes; and *oceanic*, when by the ocean.

SILT.—Mud or sand carried down by any river, and deposited either along its banks or in lakes, is called silt; and when a lake becomes filled with this matter, it is said to be *silted up*. Silt is generally applied to matter calmly or slowly deposited.

DEBRIS (French)—a term applied to the loose material arising from the disintegration of rocks.

ALLUVIAL (Lat., *luere*, to wash, and *ad*, together). Land washed or brought together by the action of water is said to be alluvial. Most of the *straths* and *carses* in Scotland, and the *dales* in England, are alluvial; as are also the *deltas* of all such rivers as the Nile, Ganges, Niger, Mississippi, &c.

SEDIMENT (Lat., *sedere*, to sit or settle down)—matter settled down from solution in water. If water containing mud be allowed to stand without agitation, the mud will gradually fall to the bottom, and become sediment. Rocks which have been deposited after this manner, such as sandstone, are said to be *sedimentary*.

DEPOSIT (Lat., *de*, down, and *positus*, placed)—applied to matter which has settled down from water. Mud, sand, gravel, &c. are all deposits, and are distinguished by the kind of agency which produced them; such as fluvial (river) deposits, lacustrine (lake) deposits, marine (sea) deposits, and littoral (sea-shore) deposits.

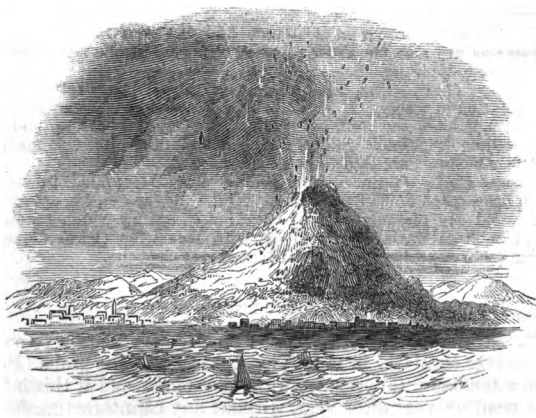
IGNEOUS AGENCIES.

66. Atmospheric and aqueous agencies may be said to exert themselves similarly in modifying the crust of the globe. Both have a tendency to wear down the dry land; and if this influence went on year after year, without any counteracting force, a time might arrive when hills and plains would be reduced to one uniform level. But the system of nature is beautifully balanced in all its parts, and as one set of agents *degrade*, another are employed to *elevate*. Thus the layers of loose material which are at one time spread out in the bottom of

lakes and seas, is at another raised into open day, to form new lands for the support of vegetable and animal existence. The principal agent employed in this elevating process is the *Igneous*, or that which depends upon some deep-seated source of fire. Hereafter we shall notice the opinions which have been advanced concerning the origin of subterranean fire ; at present we have merely to do with its sensible effects.

67. *Igneous agency may exert itself either chemically or mechanically ;* chemically, as in the production of new compounds, gaseous admixtures, &c. ; mechanically, as when it elevates and fractures the solid crust of the earth. Its mode of action may be considered under three heads ; namely, Volcanoes, Earthquakes, and Gradually Elevating Forces.

68. *Volcanoes* may be described as vents of subterraneous fire, through which smoke, gaseous vapours, cinders, ashes, stones, and rocky matter in a state of fusion, are discharged. The explosive or expansive force of the internal fire forms a vent for itself in the first instance ; this opening is termed the *crater*, and the matter discharged, gradually collecting around it, produces a mountain of a towering or conical form, like that described by the following figure.

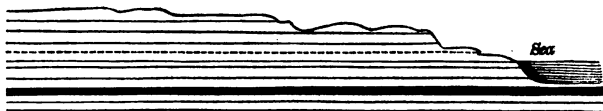


View of Mount Etna.

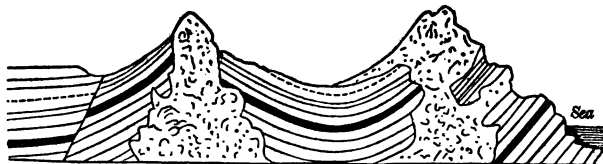
69. *Such is the general appearance of isolated volcanoes ; but they frequently occur in ranges, producing, by the union of their forces, elevated mountain chains like those of South*

America. In these ranges, some of the vents are in active operation, and others have become dormant; so that we are insensibly led from the crater vomiting forth smoke and lava to those now cold and dormant, and thence again back to distant eras when all mountain chains were produced by the same kind of forces. Indeed no one can look upon the mere outward appearance of *Ætna* and *Vesuvius* on the one hand, the Alps, the hills of central France, and the hills of the Scottish Lowlands on the other, without at once assigning their origin to similar causes.

70. *Volcanic forces not only elevate but fracture and contort* the originally plane strata, at the same time that they throw up rocky matter which is not arranged in distinct layers. It has been already stated that water has a tendency to lay down the material which it transports in flat or level strata; hence the sedimentary rocks will originally partake of this level character. Suppose, then, that the following engraving represents a part of the earth's crust not broken or upheaved by volcanic forces, the same



portion will present a very different appearance when fractured and elevated by these causes. Here the sedimentary strata are not only thrown out of their original level position,



but are bent, broken asunder, and in some places overlaid by discharges of volcanic matter; hence a very obvious distinction exists between rocks of *aqueous* and rocks of *igneous* origin.

71. *A volcano may at one time discharge ashes*, at another time rock fragments, and at a third molten lava; and it is true that these different materials may be found on its sides arranged in something like strata; but they do not present this

regularity for any distance. Sedimentary strata, on the other hand, preserve their character and continuity over many miles of country, showing a calm and tranquil origin in comparison with those masses produced by volcanic fusion. Other distinctions between aqueous and igneous rocks will hereafter be pointed out to the student; but at present he cannot fail to perceive that sand, clay, mud, and other matter deposited from water, must be more equally and flatly laid down than cinders, ashes, and lava, which are vomited forth without order or arrangement.

72. *There are at present upwards of two hundred volcanoes in active operation.* The greater number of these are to be found in the mountain ranges of South America, along the western coast of North America, and in the Southern Pacific. In central Asia there are also several vents; and *Ætna*, *Vesuvius*, and *Hecla*, are well-known examples in Europe. The number of active volcanoes is nothing, however, in comparison with what once existed; for there is scarcely a country (Italy, France, Britain, West India Islands, the Azores, Iceland, &c.) that does not give evidence of innumerable volcanic craters which have long since ceased to modify the crust of the globe. Even these dormant vents are insignificant in comparison with the still older mountain ranges of the *Grampians*, *Pyrenees*, *Uralian*, *Himmaleh*, *Andes*, and other chains which must have been upheaved by the same subterranean forces.

73. *Of the elevating power of volcanoes* we have many examples within the historical period, and comparing active volcanic hills with ancient ranges, we may arrive at some idea of the enormous power exerted by igneous forces in the earlier ages of the world. During an eruption of *Ætna*, a space around the mountain, 150 miles in circumference, was covered with a layer of sand and ashes, generally about 12 feet thick. In the first century, the cities of *Herculaneum* and *Pompeii* were buried beneath such a layer of matter by *Vesuvius*. In 1660, the philosopher *Kircher*, after accurately examining *Ætna*, and the ground adjoining its base, calculated that the whole matter thrown out by it at its various active periods would form a mass twenty times as large as the mountain itself, which is 10,870 feet high, and 30 miles in diameter at the base. From this mountain, in 1775, there issued a stream of lava a mile and a-half in breadth, 12 miles long, and 200 feet thick. At an earlier period, there was a stream which covered 84 square miles. In 1538, a large hill, since named *Monte Nuovo*, was thrown up in the neighbourhood of *Naples* in one night; and in 1759, in a district of *Mexico*, previously covered by planta-

tions, a sudden outburst of volcanic action, which lasted several months, terminated in leaving six hills, varying from 300 to 1600 feet in height above the old plain. As on land, so also in the ocean; and the student will hereafter find that many volcanoes have been known to arise from the sea, that the bottom of the sea has been upheaved by the same influence, and that many islands, such as those of the Pacific and Atlantic, are mere accumulations of volcanic matter. "Owhyhee," says De la Beche, "is a magnificent example of such an island: the whole mass, estimated as exposing a surface of 4000 square miles, is composed of lava, or other volcanic matter, which rises in the peaks of Mouna Roa and Mouna Kaa to the height of between 15,000 and 16,000 feet above the level of the sea."

74. *Earthquakes are most important geological agents*, though their origin and mode of action is scarcely so obvious as those of volcanoes. The theories which have been advanced to account for such phenomena will be elsewhere adverted to; here it is sufficient to state, that, though they occur in all parts of the world, they are much more frequent and violent in the region of active volcanoes. Earthquakes are strictly mechanical in their mode of action, upheaving some portions of the crust and depressing others, causing rents and fissures; altering the course of rivers, elevating the bottom of the sea to open day, and submerging dry land beneath the ocean. They are sometimes so gentle in their operations, that a slight tremulous motion of the earth is all that is perceived; at other times the shock is so violent, that the surface configuration of wide districts is completely altered, and the works of man become masses of ruin. Volumes might be filled with accounts of earthquakes and their disastrous consequences; we shall simply notice a few historical facts to show their importance. In 1596 several towns in Japan were covered by the sea; in 1638 St Euphemia became a lake; in 1692 Port Royal, in Jamaica, was submerged; in 1775 the great earthquake of Lisbon sank many parts of the Portuguese and African shores 100 fathoms under water; in 1819, at the mouth of the Indus, a large tract of country, with villages, was submerged, while a new tract was elevated, called the "Ullah Bund;" in 1822 about 100 miles of the Chili coast was elevated to the height of four or six feet; and in 1843 several of the West India Islands were fearfully convulsed, and a vast amount of life and property destroyed.

75. *The general effect of earthquakes*, like that of volcanic forces, is to render the crust of the earth irregular in surface,

by depressing some portions and by elevating others. It requires little effort of imagination to conceive how a level tract of country might, by a few shocks, be converted into abrupt heights, rents, chasms, and hollows, or even sunk many fathoms beneath the ocean. Earthquakes in the vicinity of the sea are generally accompanied with violent agitation of the water, and waves of enormous height are rolled upon the land (60 feet in the Lisbon earthquake), tearing up the surface, and forming masses of loose material.

76. *As earthquakes now act, so must they have done in all time past*; and if the great mountain ranges prove the existence of more extensive volcanic agency, we are warranted to conclude that earthquakes were also more frequent and disastrous in the earlier ages of the world. If fissures, chasms, and subsidences be at present produced by earthquakes, the student will have little difficulty in accounting for the numerous rents and breakings which occur in the solid strata in regions where volcanoes and earthquakes have long since ceased to exert their agency.

77. *Gradually elevating forces* appear to be intimately connected with those which produce volcanic eruptions and earthquakes. The term is applied where we find tracts of country and shores of the sea undergoing a slow process of elevation, without being accompanied with any perceptible violence. Mr Lyell has discovered instances of this kind of elevation along the shores of the Baltic, where places, which a century ago were on a level with the sea, are now several feet above it, and where even a change of a few inches has taken place since 1820.

78. *To what extent such forces may have operated in times past* we have no knowledge; and even at the present moment, differences in the relative level of sea and land may be occurring in certain districts so gradually, that they escape our observation. Wherever the sea has acted upon the land for any length of time, it forms a shore or beach, generally an inclined plane, along which the tide rises and falls. If the land be raised up, or the sea depressed, the form of this beach will be preserved, and easily traceable both from its level appearance and from the nature of the gravel, sand, and shells of which it is composed. Such ancient beaches have been found in various parts of the world, at elevations from 8 to 60 feet, clearly showing that changes in the relative level of sea and land have often taken place over vast areas, but affording little evidence whether the changes have been suddenly or gradually accomplished. Along the shores of the Forth and Clyde in Scotland, the

east coast of England, and the coast of France and Portugal, there is a very remarkable beach of this description, from 40 to 50 feet above the present sea-level, and presenting a sort of step or terrace, which is easily traceable sometimes for miles together. This terrace is composed of rounded pebbles, gravel, sand, and sea-shells, and such material as usually compose the beaches at the present day.

79. *As some parts of the land may be elevated, so others may be depressed*; and consequently we find stumps of trees under the present sea-level, clearly showing that the land on which they grew had been submerged. But whether these ancient elevations and depressions have been accomplished in one hour or in many years, whether quietly or with violence, geologists have not yet been able to determine.

EXPLANATORY NOTE.

VOLCANO, from *Vulcan*, the god of fire, who was supposed by the ancients to reside in a cavern under Mount Ætna, and to forge thunderbolts for Jupiter.

LAVA, an Italian term, now universally applied to those masses of melted matter which are discharged by volcanoes during an eruption. Loose fragments of rocks, cinders, dust, and ashes, are comprehended under the term *scoria*.

CRATER (Gr., *krater*, a cup or bowl)—the mouth or vent of a volcano; so called from the resemblance which its shape bears to an ancient drinking bowl. The craters of volcanoes have, in general, one edge a little lower than the other, owing to the prevailing winds carrying the greater portion of the light material to the opposite side.

ORGANIC AGENCIES.

80. Compared with the other classes of agents which have been described, the Organic are comparatively unimportant in modifying the crust of the globe. They exert an elevating or accumulating influence, and may act either on the dry land, in fresh or in salt water, according to the nature of the vegetables or animals from which they result. They are comparatively slow in their operations, but produce the most interesting class of phenomena with which geological research has made us acquainted. Organic agency presents itself under two great heads—namely, Vegetable and Animal.

81. *Vegetable growth acts in two ways*: first, by forming accumulations of matter, such as peat; or, second, by protecting the soil from the degrading power of rains and winds. Extensive areas of sand-drift would be continually shifting, were it not for the vegetable sward which gathers over their surface; and all soils, during seasons of drought or rain,

would be liable to be blown or washed away, were it not for the grassy turf which covers them. Marine plants are extremely perishable, and exert no perceptible influence on the earth's crust. Terrestrial plants are of a very different character both in point of size, number, and material; and to them are chiefly owing the vegetable deposits in all ages of the world.

82. *Trees and plants are annually carried down by rivers, and deposited* along with the layers of sand and mud which have already been noticed. The *rafts* of the Mississippi are frequently several miles in length, and from 6 to 10 feet thick, being composed of trees, roots, and brushwood. All marshes and shallow waters give birth to innumerable aquatic plants, which grow and decay from year to year, till, in the course of centuries, their remains form thick accumulations of peat. Peat bogs, of many miles in surface, and from 4 to 20 feet in thickness, are frequent in Scotland, Ireland, and other countries, and contain trees and the remains of animals which once inhabited the country. Vegetable growth is greatly influenced by climate, being more prolific and gigantic in warm than in cold regions, and being also entirely different in character. While, therefore, peat is forming in the bogs of Ireland, the Mississippi is carrying down the pines of America, and the Ganges the palms, canes, and tree-ferns of the Indian jungle.

83. *Of the vegetation of past eras* we can only judge from the fossil remains found in the solid rocks; and, comparing that of the coal strata with what now exists, we are warranted in concluding that the earth has at certain times nourished a more luxuriant and gigantic vegetation. Indeed coal, as will hereafter be shown, is just as much a mass of altered plants and trees as peat is; and when the student is told of many beds of coal lying one above another, some of which are ten, fifteen, and twenty feet in thickness, he may readily conjecture what an immense mass of vegetation has been compressed into this one formation. The present formation of vegetable deposits, and the dependence of plants upon temperature and climate, are facts which it is necessary to bear in mind; otherwise it will be impossible to account for many appearances which are presented in the stratified crust of the globe.

84. *Animal life is also an active agent in adding to the solid material of the globe.* Generally speaking, the remains of animals are very perishable; hence, though their bones, teeth, and scaly coverings are numerous found as fossils, yet these form a mere fraction of the rocks in which they are imbedded.

It is not in this light, therefore, that animal existence may be said to be influential in modifying the crust of the earth ; and we may reckon of slight importance all the skeletons of the larger animals which are deposited along with the mud, sand, and gravel in the bottoms of existing lakes and seas. It is the minutest forms of life which are mainly instrumental in forming deposits of this class ; such as the coral-insect, shell-fish, and some crustaceous animals.

85. *By the labours of the coral animalcule* are formed those extensive reefs of solid coral, or limestone, well known to the navigators of the Pacific. These reefs rise in masses of various shapes ; sometimes as islets, at other times as circular belts enclosing a lagoon or lake of salt water, but more frequently in long abrupt ridges from 20 to 100 feet in thickness. The great reef, which follows the line of the northern coast of New Holland, is more than 1000 miles in length, in the course of which there is one continued portion exceeding 350 miles, without a break or passage through it. The animalcule is scarcely so large as a pin's head ; it is star-shaped, is of a soft gelatinous structure, and myriads of them unite in their operations to form a single branch of coral. By examining a piece of coral, its surface will be found dotted with small star-like openings : each of these contains a single animal, and the space between them is covered by the membrane above referred to. These animalcules have the power of secreting limy matter from the waters of the ocean ; they are incessantly at action, and many of the reefs rise several feet in the course of a few years. They do not commence their labours at great depths, but attach their structures to rocks from 60 to 100 feet below the surface ; and thus the coral reefs partake of the shape of the submarine ridges on which they are founded. As their structures approach the surface, the waves and currents of the ocean detach large pieces, which are either drifted on the land, and form coral-beaches, or are piled upon the surface of the growing reef, till it rises above the sea. When the animal reaches the surface it ceases its operations, and the subsequent elevation into islands and dry land is performed by the waves and tides, and by the elevating forces described in the preceding section.

86. *Coral is almost entirely composed of pure limestone*, and is found in all stages of solidity, from an open porous mass, with the live animal upon it, to a hard and compact limestone, with scarcely a trace of its animal origin discernible. There are many species of the coral animalcule, each variety rearing its structure after a different form ; and from this fact such names have been given as tree coral, fan coral, organ-pipe

coral, brain coral, &c. Whatever be the shape, the substance formed, and their mode of action, is the same. They are found largely over the Southern Pacific, in the Indian Sea, the Red Sea, and other portions of the ocean. As at present, so in former ages of the world; and the student will hereafter find that many of the beds of limestone now deep in the crust of the globe, have been formed by the same kind of organic agency.

87. *Shell-fish, like the coral animal, have the power of secreting limy matter from the ocean.* In the former case, the secreted matter forms a covering or enclosure for the animal; in the latter, the animal is external, and the structure forms a mere groundwork for its operations, and a wider field for the increase of its kind. There is an immense variety of shell-fish, but only a few varieties exist in great numbers, and it is by the agency of these that shell-beds are formed. The oyster, muscle, and cockle, are familiar examples; they live in great shoals or beds, covering from a few acres to many miles of the bottom of our seas and friths. Zoologists have found that most shell-fish live in shallow waters around the shores; and from this habit they are more liable to be covered by the material borne down by floods and rivers. In raised beaches, and in deltas, we actually find such accumulations of shells, sometimes several feet in thickness, and presenting the same appearance as when they lived and multiplied in the waters. If, then, extensive layers of shell-fish now exist, and if they are sometimes found imbedded in the alluvial matter of deltas and lakes, the student will be better enabled to account for the occurrence of thick masses of shells, or limestone wholly composed of shells, among the solid rocky strata.

88. *Although corals and shell-fish are the most important animal agents* in adding to the material of the earth's crust, yet the exuvie of other animals must not be overlooked; for, it is often from the occurrence of these alone, that we are enabled to infer as to the former conditions of the world. Thus, the remains of elephants, lions, and tigers, may be carried down by the waters of the Ganges, and deposited in its delta; those of the rhinoceros, hippopotamus, and ostrich, by the Niger; and those of the buffalo, elk, and reindeer, by the Mississippi; while the rivers of Britain convey no such remains to the ocean. The sand, mud, and gravel of all these deltas are very much alike; and if they should hereafter form rocks, the geologist could tell of the condition of the country in which they were formed only by the kind of fossils which these rocks contained.

89. *The formation of coral-reefs and shell-beds is a gradual and ordinary operation ; but shoals of other fishes may be entombed during violent storms, or during submarine volcanic eruptions, which are attended by noxious vapours, heat, and a suffocating agitation of the mud of the ocean. The modes in which vegetable and animal life may affect the crust of the globe are extremely complex and varied, but the above are the most obvious and important.*

RECAPITULATION.

90. *As detailed in the preceding section, the causes chiefly employed in modifying the structure of the globe may be divided into four classes—ATMOSPHERIC, AQUEOUS, IGNEOUS, and ORGANIC. The former two exert a degrading or wasting influence, and if not counterbalanced by other forces, would ultimately wear down the dry land to a level with the ocean ; the latter exert an elevating or accumulating influence, and thus maintain that elevation and diversity of dry land essential to animal and vegetable life. To assist the memory, these agents may be briefly arranged as follows :—*

DEGRADING CAUSES.		ELEVATING CAUSES.	
<i>Atmospheric.</i>	<i>Aqueous.</i>	<i>Igneous.</i>	<i>Organic.</i>
Winds, Frosts, Heat and Light, Gaseous Admix- tures.	Rains, Snow, &c. Springs, Rivers, Waves, Currents, Tides.	Volcanoes, Earthquakes, Gradually elevat- ing forces.	Vegetable accu- mulations, as peat, &c. Animal, as coral- reefs, shell- beds, &c.

91. *If, then, on the one hand, winds, frosts, rains, rivers, and waves be continually wasting down the solid crust, and depositing the debris in layers along the bottom of lakes and seas ; and if, on the other, these layers be consolidated by pressure, by chemical processes, or by heat, and be then elevated into dry land by volcanoes and earthquakes, it must be obvious that the surface of the globe is in a state of perpetual change. These changes may be slow and imperceptible, or sudden and obvious ; but in either way the appearances exhibited by the earth's surface must be very different now from what it was many thousand years ago. What was then covered by the ocean, may now be dry land ; and what was dry land, may have since been ocean, and may now be dry land again. These changes will be manifested by the kind of layers or rocks deposited at each successive period in the bottom of the sea ; hence the geological history of the*

world can only be discovered by the study of these strata. But as these strata were upheaved by volcanic agency, rocky masses of igneous or volcanic origin are frequently mingled with them ; hence we find not only stratified rocks from deposition in water, but unstratified, the result of igneous fusion. Again, all strata originally deposited by water will contain more or less the remains of plants and animals which flourished during the period they were deposited ; and the consideration of these petrifications affords the geologist an idea of the kind of life which then peopled the surface of the earth, or inhabited the waters. These unstratified and stratified rocks, with the animal and vegetable remains which they contain, form the solid crust of the globe—the structure, composition, and formation of which it is the province of geology to consider.

EXPLANATORY NOTE.

SECRETION (Lat., *secretus*, separated or set aside). Both animals and vegetables are said to secrete certain substances. Coral, for example, is an animal secretion composed of lime, which the animalcule has the power of separating from the water of the ocean ; resin and gum are vegetable secretions.

EXUVIÆ (Lat., *cast clothes*). In Zoology this term is applied to the external integuments of animals which are periodically shed or cast off, such as the skin of the snake, the crustaceous covering of the crab, &c. ; but in geology it is employed to designate fossil animal remains of whatever description.

MINERAL SUBSTANCES COMPOSING THE EARTH'S CRUST.

92. **THE MINERAL OR ROCKY SUBSTANCES** which compose the crust of the globe are exceedingly numerous and varied. They are commonly known by the name of rocks, minerals, metals, earths, and salts ; but, geologically, are all comprehended under the general appellation *rock*. The individual minerals and elementary substances of which rocks are composed, come more appropriately under the sciences of mineralogy, metallurgy, and chemistry. Passing over the mere surface soil, and proceeding downwards to the greatest known depth, the solid crust may be said to be composed of two great classes of rocks—those arranged in layers, and those occurring in irregular masses ; in other words, the **STRATIFIED** and **UNSTRATIFIED**. The stratified are those which have been formed from deposition in water ; hence they are also known by the terms *aqueous* and *sedimentary*. The unstratified are those which have been formed by fire, and are also known by

the terms *igneous* and *volcanic*. The following engraving represents the appearance which the stratified and unstratified rocks present in a section of the earth's crust.



93. *All rocks, whatever be their origin, have three characters under which they are viewed by the geologist—namely, the Mechanical, Mineral, and Chemical; and though it is impossible, in an elementary work of this kind, to enter fully into the consideration of these characters, still it is necessary that the student should be in some degree acquainted with the technical terms which are employed to designate these characters.*

94. *The mechanical structure of rocks* is that which presents itself in the general appearance of the mass as it occurs in the earth, or in portions of the mass when it is broken up by artificial means. It has nothing to do with the composition, and merely considers the appearances presented, whether the rock be roofing-slate, chalk, or coal. For example, some rocks are arranged in layers, and these layers can be split up into still thinner plates, as slate; others occur in columns, like the basalt of Staffa and the Giant's Causeway; and these columns can be broken up into small prismatic pieces. This structure is purely mechanical, and has been divided by geologists into the external and internal—the former having reference to the mere outward form, and the latter to the shape of the smaller fragments into which the mass can be broken. The external structure of coal, for instance, is stratified, but the internal structure varies; caking coal breaking up into small cubes or square pieces, splint coal into thin slaty divisions, and cannel coal into irregular fragments, having a shell-like surface.

95. *The terms employed to describe these varieties of structure* are useful, in as far as they enable one writer to make himself understood by another. The following are those of most frequent occurrence :—

Massive, occurring in large masses of no determinate form, as granite.

Amorphous, without any regular shape; amorphous and massive are very similar terms.

Cuboidal, in square masses resembling cubes, as some greenstones.

Prismatic, occurring in masses, with faces and angles like a prism.

Columnar, in columns or pillars, like basalt. Where the pillars are not very distinct and regular, the term *sub-columnar* is used.

Stratum, bed, seam, and layer. These are nearly synonymous terms, all conveying the idea of being spread or laid out in parallel masses, as sandstone, slate, &c.

Schistose, fissile, slaty, laminar, are employed to describe rocks capable of being split up into thin plates or divisions like slate.

Foliated, when the laminæ or slates split up into still thinner leaves.

Squamosæ, when the fragments have a scaly appearance, like mica.

Fibrous, having a fibrous texture, like asbestos; *acicular*, when the fibres have a distinct needle-shaped appearance.

Vesicular, cellular, when the texture of the rock is full of small cells or vesicles.

Granular, when the texture is made of distinct grains, as granite.

Saccharoid, when the grains have a uniform crystalline aspect, like loaf-sugar.

Porous, of an open texture, or full of pores, as pumicestone.

Friable, when easily broken down; *earthy*, of a soft dull texture; and *compact*, when of a close and firm texture.

96. *The mineral character of rocks* has reference to the number and aggregation of the simple minerals of which they are composed. A piece of granite, for example, is composed of distinct crystals of *felspar, quartz, and mica*, which are said to be simple minerals. In general, minerals occur in fixed shapes, as cubes, prisms, &c. in the igneous rocks; while in the aqueous, their edges and angles are broken and water-worn. Some rocks are *simple*—that is, composed only of one mineral, such as limestone; others *compound*, or formed of several minerals, as granite; and some, apparently simple, are in reality compounds of several minerals minutely blended together, as certain kinds of sandstone.

97. *There are many hundreds of simple minerals* differing from each other in shape, colour, lustre, hardness, composition, &c. The consideration of these characteristics more properly constitute the science of mineralogy; but it is impossible for the student in geology to make much useful progress without being acquainted with those minerals which enter most largely into the composition of rocks. These are the following:—

Quartz; the hard white crystals of granite, and the white grains of sandstone, are of quartz.

Felspar; the soft grayish crystals of granite, which can be easily scratched, are of felspar.

Mica; the glistening, scaly, and transparent portions of granite are of mica; it occurs in minute scales in many sandstones, giving to them a silvery aspect.

Hornblende, a black or dark-green mineral found in some granites in

the room of mica ; granite is then called *syenite*. Hornblende is so named from its horny fracture.

Actynolite, so called from the pointed or thorny appearance of its crystals ; it is of a greenish-gray colour, and found in some of the early slates.

Augite, a greenish mineral found in many igneous rocks ; it is the type of a class to which hornblende and actynolite belong.

Diallage, also called *Schiller Spar*, an olive, blackish, or yellowish-green mineral of a foliated structure, and having a metallic lustre.

Schorl, occurs in black prismatic crystals ; is brittle and lustrous, and becomes electric by heat and friction.

Chlorite, so called from its greenish-black colour ; it is either of a crystallised or foliated structure ; and in the latter state it forms the greater portion of that greenish slate called chlorite slate.

Green-earth, a greenish earthy mineral allied to chlorite, which enters largely into the composition of many trap-rocks.

Talc, a transparent mineral resembling mica, but softer, and not elastic.

Steatite ; all rocks containing this mineral feel greasy or soapy, and are thus easily distinguished ; they are sometimes called *soap-stones*.

Garnet, a reddish or wine-coloured mineral found in some mica slates and volcanic rocks.

Carbonate of lime ; pure marble, chalk, &c. are carbonates of lime.

Carbonate of magnesia ; lithographic limestone is a compound of carbonate of magnesia and carbonate of lime.

Sulphate of lime ; gypsum, or plaster of Paris, is sulphate of lime.

Chloride of sodium ; common salt is chloride of sodium ; it is found in sea-water, and in masses constituting rock-salt.

Bitumen, an inflammable mineral, found either liquid, as in petroleum or rock-oil ; solid, as in asphalt ; or mixed, as in common coal.

Iron, oxide and sulphurets of ; rust is an oxide of iron ; pyrites, or those little yellow cubes found in roofing-slate, are sulphurets.

98. *The most abundant rocks* are formed by the aggregation of the above minerals. It would be impossible to convey an adequate idea of these rocks by a mere verbal description ; and at this stage the student should endeavour to make himself familiar with the following rocks (of which there are many varieties), by the inspection of actual specimens :—

GRANITE,
SYENITE,
GREENSTONE,
BASALT,
HYPERSTHENE ROCK,
DIALLAGES ROCK,
SERPENTINE,
WACKE,

FELSPAR ROCK,
CLAYSTONE,
HORNSTONE,
PITCHSTONE,
GNEISS,
MICA SCHIST,
CHLORITE SCHIST,
HORNBLLENDE SCHIST,

QUARTZ ROCK,
SANDSTONE,
CLAY-SHALE,
SLATE,
FLINT,
CHERT,
LIMESTONE,
COAL.

99. *The chemical character of rocks* has no reference either to their mechanical structure or mineral aggregation. According to the deductions of chemistry, all bodies in nature, whatever their structure or appearance, are composed of

fifty-four simple or elementary substances. Granite, mineralogically speaking, is composed of quartz, felspar, and mica; but these three minerals are each composed of several chemical elements—quartz, for example, being a compound of the gaseous body oxygen, and a metal called silicium.

100. *Of the elementary bodies*, under the ordinary pressure and temperature of the atmosphere, there are—

Five *gaseous*—hydrogen, oxygen, nitrogen, chlorine, and fluorine;

Seven *non-metallic*, liquids and solids—bromine, iodine, sulphur, phosphorus, selenium, carbon, and boron;

Thirteen *solid metalloids*, which unite with oxygen to form the earths and alkalies—sodium, potassium, lithium, aluminum, silicium, yttrium, glucium, thorium, calcium, magnesium, zirconium, strontium, barium;

Twenty-nine *metals*, which are all solid save mercury—manganese, zinc, iron, tin, cadmium, arsenic, antimony, copper, molybdenum, uranium, tellurium, chromium, cerium, nickel, vanadium, cobalt, lead, tungsten, titanium, mercury, columbium, bismuth, osmium, silver, palladium, rhodium, platinum, gold, and iridium.

101. *Only a few of the fifty-four so-called elements* enter largely into the composition of the rocky masses which constitute the crust of the globe. The most prevalent are oxygen, carbon, sulphur, aluminum, silicium, potassium, sodium, calcium, magnesium, and iron. Of these, oxygen is by far the most prevalent; it is found in combination with every other substance, and is supposed to constitute fully one half of the ponderable matter of the globe.

102. *From what has been stated* in the foregoing paragraphs respecting the mechanical, mineral, and chemical characters of rocks, it will be seen how necessary a knowledge of these is to the right investigation of the constitution of the earth. It is true that geological research may be carried on without an intimate knowledge of mineralogy or chemistry, but it is evident that a certain amount of mineralogical and chemical information will greatly assist the pursuit. To illustrate this by a familiar example:—Granite, geologically speaking, is unstratified, massive, granular, composed of several ingredients; from its general structure, it is regarded as arising from igneous fusion, and is considered as the basis of all the stratified rocks. To the mineralogist these facts are of little importance; he proceeds to consider it as composed of three distinct minerals—quartz, felspar, and mica—and to arrange these minerals into classes according to their shape, colour, lustre, hardness, &c. But a knowledge of these minerals greatly assists the geologist; for, while he finds them regularly crystallised in granite, he finds

them broken and water-worn in gneiss, and concludes that gneiss must have been formed of the disintegrated particles of granite. Again, to the chemist, geological conclusions and mineral classification are but secondary objects; he takes up the simple minerals, and resolves them into their simplest elements, and finds that quartz consists of silicium and oxygen; felspar of silica, alumina, lime, potash, oxide of iron, and water; mica of silica, alumina, magnesia, potash, oxide of iron, and oxide of magnesia. A knowledge of these chemical facts also greatly assists the geologist, as they enable him to account for many changes which take place among rocks, and from whence their materials have been derived. For instance, iron and clay-slate are not perceptible in granite; yet, by chemical means, the ores of iron and clay-slate may both be derived from the felspar and mica which constitute the granite.

EXPLANATORY NOTE.

CHARACTERS OF ROCKS.—The student will readily learn to distinguish the *mechanical* characters of rocks, that is, that which relates to their external forms and internal texture. For example, he can have little difficulty in determining whether a rock be columnar or massive, granular or fibrous; he may, however, frequently be puzzled to decide as to its *mineral* composition. Certain simple minerals, as quartz, mica, iron pyrites, &c. are easily recognised; but in the majority of cases many tests are required, such as taste, smell, adhesion to the tongue, colour, lustre, form, hardness, and so on. For this purpose a knowledge of mineralogy is necessary; an acquirement which, at this stage, the student is not expected to possess. It will therefore be advisable that he familiarise himself with the most prevalent minerals and rocks by the inspection of actual specimens, cabinets of which can be obtained from the dealers for a trifling sum. To ascertain the precise *chemical* constitution of any rock, is a matter requiring considerable experience in the laboratory; but possessed of a retort and spirit-lamp, a blowpipe, a few test-tubes, and acids, the student may readily detect the presence of such substances as lime, iron, copper, lead, sulphur, soda, potash, &c.

MEANS OF GEOLOGICAL INVESTIGATION.

103. *The means placed within man's reach for investigating the history of the globe*, are of a very satisfactory description. The accessible crust being for the most part formed of stratified rocks occurring in definite order one above another, each composed of certain minerals, and containing different kinds of

fossil plants and animals, it enables us to determine the relative time required for the formation of certain strata, and to predict, from the kind of fossils, what must have been the state of the earth as to climate and other geographical features at the period when these remains were imbedded. Strata, for example, which contain the remains of marine shells and fishes, indicate that they have been deposited in seas; those containing freshwater shells and plants, that they have been formed in lakes and estuaries; and as certain plants and animals now flourish in a tropical climate, so will similar fossil remains indicate that they have lived under a similar temperature. Fine-grained and thinly-laminated beds, such as clay-slate, must have been deposited under different conditions from a bed of gravelly conglomerate; and the circumstances which went to the formation of coal, must have been widely different from those under which chalk was formed. Further, some strata lie in a slanting position; and as we know that all matter deposited from water arranges itself in nearly horizontal beds, these strata must have been turned up by some elevating cause. No extensive elevation of the crust, however, can take place without causing rents and fractures, contortions, and other dislocations of the strata; and from the magnitude of these, some idea may be formed of the volcanic forces which caused them. Thus it is, by the stratified rocks, the order in which they occur, the kind of material of which they are composed, and the organic remains imbedded in them, that the geologist is enabled to proceed with his investigations.

104. *Had the stratified rocks lain in regular undisturbed succession*, like the coats of an onion, man would have made but little progress in deciphering their history, as the greatest perpendicular descent he has yet made into the crust of the earth does not extend to half-a-mile. But as these rocks are thrown up into slanting and irregular positions, so that the lowest are brought to the surface equally with those most recently formed, geologists have been able to collect a regular series of stratified rocks, from those deposited, as it were, but yesterday, downwards to the unstratified granite which forms their basis. There are two great means of investigation: *artificial sections*, as exhibited in coal-pits, quarries, and tunnels; and *natural sections*, as occasionally exposed by the sea-shore, by ravines, and by river channels.

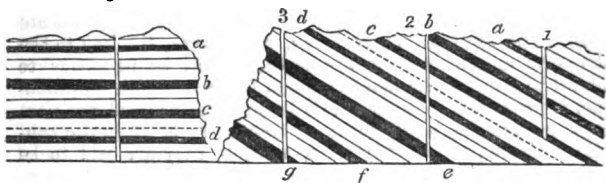
105. *Artificial sections* assist geological inquiry in this manner:—Suppose a series of strata, *a, b, c, d*, should occur in a horizontal position (fig. A), we may become acquainted with their composition and order by a shaft or pit piercing them; but by this means we cannot arrive at any great depth

into the earth's crust, from the expense of working deep shafts, and the difficulty of carrying off their water. Were the same series of rocks, however, thrown up in a slanting position

Fig. A.



Fig. B.



(fig. B), then every shaft that pierced them would add to the amount of our information. For example, the shaft No. 1 pierces the coal-beds *a*, *b*, and *e*; No. 2 the coal-beds *c*, *d*, and *e*; and No. 3 the coal-beds *e*, *f*, and *g*. Now, by adding the results of these comparatively shallow shafts, they would furnish us with information respecting the whole series of strata from *a* to *g*, and which, in a horizontal position, human means never could have reached. By collecting and comparing the results of many shafts and borings, geologists are enabled to map out sections of extensive districts, and so become acquainted with the structure of the earth to enormous depths.

106. *The most extensive and satisfactory sections of stratified rocks are those presented by ravines, and by the sea-shore. Thus, in tracing the course of a river, as represented by the following engraving, the geologist would become acquainted*

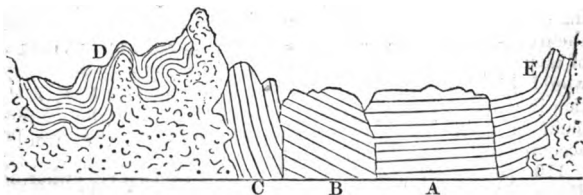


with several series of rocks, and see their mineral and fossil characters much more distinctly than by any shaft or boring. Here the river bank exposes the strata from C to D in regular succession, where it is obvious, had they been in a horizontal position, only two or three beds would have been cut through by the action of the water. Such sections are numerous in hilly countries and along the sea-coast; and in these situations should the student make himself familiar not only with the succession of strata, but with the modes and peculiarities

of stratification, which can never be perfectly understood unless from actual observation.

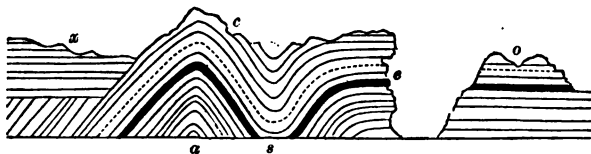
FORMS OF STRATIFICATION.

107. *The stratified rocks* being, as it were, the key to the structure and history of the earth, it will be necessary to advert to some of the more common forms in which stratification is presented. When strata lie in a flat or level position, they are said to be *plane* or *horizontal*, as at *A* in the sub-joined figure; when they slant, as at *B*, they are said to be



inclined, and the angle which they form with the horizon is called the *dip*, or angle of inclination; when highly inclined, as at *C*, they are termed *vertical*, or *edge strata*, as appearing to be set on edge; when bent and twisted, as at *D*, *contorted*; and when suddenly bent up by subterranean forces, as at *E*, they are said to be *tilted up*.

108. *Strata which dip in two opposite directions* from a common ridge, as at *a*, are said to form an *anticlinal axis*, or *saddle-back*; when dipping to a common point, as at *s*, the axis is



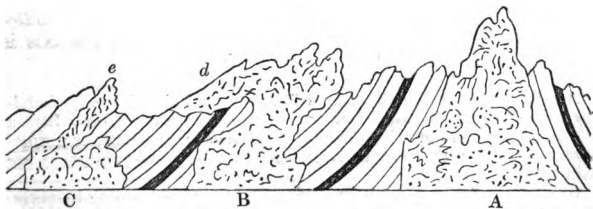
termed *synclinal*, and the hollow so formed a *trough* or *basin*. The headland, or bluff, formed by the abrupt termination of a series of strata, is called an *escarpment*, as at *e*; and beds lying apart from the main series to which they belong (*o*), *outliers*. Where a stratum comes to the surface, as at *c*, it is said to *crop out*; and the part exposed forms the *crop* or *outcrop*. Strata are said to be *conformable* when they are arranged

parallel to each other ; but *unconformable* when one set of beds overlies a lower series, without any conformity to the position of the latter. The strata at *x* are unconformable to those upon which they rest. There are several other terms applied to the position and inclination of stratified masses, but the above are those which most frequently occur.

POSITIONS OF UNSTRATIFIED ROCKS.

109. *As all stratified rocks were originally laid down in a position nearly horizontal*, the different inclinations and contortions described above must have been produced by elevating or igneous causes. Whether the upheaving forces exerted themselves through volcanic vents, accompanied by discharges of unstratified or igneous rock, or simply as earthquakes, they would produce other appearances than mere change of position in strata. These appearances are generally known by the name of *fractures*, or *disruptions*, and may or may not be accompanied by discharges of igneous rock.

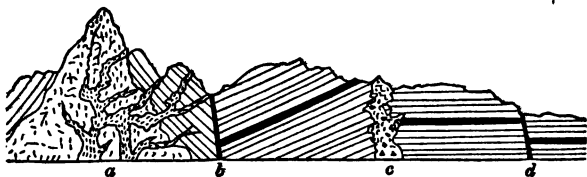
110. *Discharges of igneous rock* present themselves either as *disrupting*, *interstratified*, or *overlying* masses. In the accompanying section, *A* is simply a disrupting mass, or mountain range, by which the original strata are broken asunder ; *B* is partly a disrupting mass, and partly overlying, as it overlies the strata at *d* ; and *C* is both disrupting and interstratified, part of the fused mass appearing between the strata at *e*. Disrupting masses are caused by the expansive force of the fused mate-



rial from beneath ; overlying masses by the rock spreading itself, when in a liquid state, over the surface of the strata ; and interstratified by overlying masses being covered by a new deposition of strata. Sometimes there is a *pseudo* or *false interstratification* ; that is, when the expansive force of the igneous rock has raised one set of strata from another, and inserted itself for some distance between them. In either case

the interstratified igneous rock presents no regularity or continuity of stratification, and is easily distinguished from rocks formed from sediment in water.

111. *Fractures of the strata* caused by subterranean forces are known by the terms veins, faults, dykes, slips, hitches, &c. In the subsequent figure, *a* is a suite of veins traversing unstratified and stratified rocks; *b* a fault, or dislocation, on each side of which the strata are thrown at different inclinations; *c* a dyke, composed either of igneous rock injected from below, or of clay and gravel washed in from above, also accompanied by an alteration of the dip; and *d* a hitch or



slip arising from a portion of the strata having been thrown down to a lower level without any change in the inclination. Of course the phrase *thrown down* is merely relative; for while the strata on the right of *d* appear to be thrown down, those on the left seem to be thrown up. The mining terms, *up-throw* and *down-throw*, therefore, refer to the same phenomenon, and are used according to the position from which the strata happen to be viewed.

EXPLANATORY NOTE.

ANTICLINAL (Greek, *anti*, on opposite sides, and *clino*, I bend)—bending towards opposite sides, such as strata from a common axis. Strata bending south and north from one ridge form an anticline, or saddle-back; but when they dip in every direction from one point, they are said to be *quadriversal*.

SYNCLINAL (Gr., *syn*, together, and *clino*, I bend)—bending together, or towards one point, such as the sides of a basin towards the bottom.

DISRUPTING (Lat., *dis*, asunder, *ruptus*, broken)—breaking or forcing asunder.

DISLOCATION (Lat., *dis*, asunder, *locus*, a place)—displaced, or put out of its original or regular position.

DYKE (Scottish, *dyke*, a wall or fence)—applied to those interruptions which the miner meets with in his progress, from their appearing to wall off one part of a coal-field from another. Sometimes these dykes are only a few feet in thickness; at other times they are as many yards.

ORYCTOLOGY—SCIENCE OF FOSSILS.

112. *Fossils, whether vegetable or animal, generally partake of the character of the rocky substances in which they are imbedded; that is, if occurring in limestone, they will be more or less calcareous; if in coal, more or less bituminous; and so on of other substances. It must not be supposed, however, because a plant or animal is found in limestone, that it will be always wholly calcareous, or because it is found in coal, that it will be bituminous; the fact is, that fossils often present very irregular characters, the organic substance being sometimes entirely destroyed, leaving only its cast or impression. But whatever changes they have undergone, they may, for the sake of convenience, be arranged into three classes; namely, petrifications, converted into stony matter; bituminizations, converted into bituminous matter; and metallizations, where the substance of the fossil, whether stony or bituminous, is pervaded by some metallic substance.*

PETRIFICATION, BITUMINIZATION, AND METALLIZATION.

113. THE PROCESS OF PETRIFICATION consists in the infiltration of stony matter into the pores of bone or vegetables. In some instances, the animal or vegetable substance has been almost entirely dissolved, and the stony matter so gradually substituted, that the petrification presents a perfect resemblance in its minutest parts to the original structure. Petrification has been artificially attempted, by burying bones in mud, clay, and lime; when it was found that at the end of one year the bones had become harder and heavier, and scarcely distinguishable from true fossils. Springs containing lime in a state of chemical solution are familiar examples of petrifying agents, when they convert pieces of moss, straw, twigs, and other bodies, into limy or calcareous matter. Lime is one of the most prevalent petrifying agencies; but wood is often found converted into flint, or silicified; and many fossil trees are mere masses of fine-grained sand or quartz.

114. *The organic structure of plants and animals is not destroyed by petrification, as has been proved by many experiments. For example, slices of fossil trees have been made so thin as to be semi-transparent, and thus show the traces of vegetable fibre; and fossil zoophytes have been suspended in acids till the whole of the lime was dissolved, leaving the animal tissue distinct in its original form, and sometimes*

in its original colour. From this it will be perceived that the structure of the organism always more or less remains, and forms a basis for the petrifying solution which thoroughly pervades it, without disturbing the arrangement of those parts on which its characteristic form depends. It is this form or external character which enables geologists to compare and classify fossils with existing plants and animals.

115. *Bituminization* is that process by which vegetables insensibly lose their organic structure, and pass by a chemical process into bitumens; that is, into inflammable substances, of which coal, mineral pitch, asphalt, &c. are examples. Bituminization may sometimes be regarded as a sort of petrification, as when substances not originally vegetable are impregnated with bituminous matter, such as fossil fishes found in bituminous slate. But bituminization proper is totally different, and refers only to a certain change which vegetables undergo, by which they more or less lose their vegetable texture, and are converted into solid or liquid bitumen. To render this more evident by analogy:—If a piece of animal muscle be buried in the earth, where it obtains sufficient moisture and warmth, and is wholly excluded from the air, it is soon changed into a fatty wax-like mass (called *adipocere*, from the Latin, *adeps*, fat, and *cera*, wax), in which no trace of animal fibre is present. In like manner, if vegetable matter be excluded from the air, and subjected to heat and moisture, it is gradually converted into a black viscous and inflammable substance, called *bitumen*. This bitumen is found in all states of purity: pure and limpid as naphtha, oily as petroleum, viscous or sluggy as in mineral pitch or asphalt, elastic as in mineral caoutchouc, and solid as in jet, cannel, and common coal; the latter of which varies according to the quantity of earthy matter mixed up with it. Amber and certain mineral resins are also the results of bituminization.

116. *The process of bituminization* cannot be fully understood without a considerable knowledge of chemistry: a few of the changes which decomposing vegetables undergo may, however, be enumerated. If vegetables are left on the surface of the earth exposed to air and moisture, they soon putrefy, and fall down into a black pulverulent matter, called *vegetable mould*. Again, if they are subjected to moisture, and partially excluded from the atmosphere, petrification does not take place; but a half-bituminous substance is formed analogous to *peat-moss*. Lastly, if vegetable matter be buried at depths beyond the influence of the air, neither mould nor peat is formed, but *bituminous matter* in various degrees of purity and perfection

is obtained. This process of bituminization has been defined as "a fermentation peculiar to vegetable matter placed in such situations as not only to exclude the external air, and secure the presence of moisture, but prevent the escape of the more volatile principles." Every one is familiar with the kind of fermentation which takes place when half-dried hay is thrown into a heap; it gives off heat, becomes black in colour, and frequently takes fire and is consumed. It is this heating process which produces the bituminous fermentation when the vegetable mass is excluded from the air, and subjected to moisture and pressure. Animal remains may be impregnated with bitumen; but it is vegetables alone which can be converted into mineral pitch, jet, and common coal; and these substances are more or less pure, according as earthy matter may be mingled with them.

117. *Metallization* is that process by which fossil remains become impregnated with, or wholly converted into, metallic substances. The student must be aware that metals can be dissolved or held in a state of solution, as well as in a state of fusion. In this state of solution they are borne about by the waters which hold them; and these waters either percolate through the earth, or mingle intimately with the substances which compose it. The strata which imbed fossils generally contain metallic substances, such as iron; animals and vegetables, when in a state of decay, give off certain gases; water is always present in greater or less abundance; and thus the metallic substances, the gases and water, by chemical union, form compounds, which enter thoroughly into the pores of the fossils, and so convert them into a metallic, instead of stony or bituminous state. The changes thus effected are sometimes partial, the external parts of the fossil being metallised, whilst the interior remains stony or bituminous; sometimes the fossil is simply covered over with an incrustation of metallic salts, such as iron pyrites; at other times the original elements of the fossil remain thoroughly imbued with the metal; while not unfrequently the whole substance is rendered metallic, every trace of organic structure being obliterated.

118. *By these three processes—Petrifaction, Bituminization, and Metallization—*have the remains of plants and animals, which once lived and grew on the face of the globe, been preserved in the strata which compose its crust. So complete in many cases is this system of preservation, that the geologist is enabled not only to discover their form and structure, but to decide with certainty as to their habits, and to say whether they were fresh-water or marine, whether terrestrial or

aquatic, whether they lived and flourished under a tropical or under a temperate climate.

FOSSIL BOTANY AND ZOOLOGY.

119. Before the geologist be qualified to decide as to the nature of fossil plants and animals; before he can classify them and compare them with those now existing, or determine all the conditions under which they must have flourished, he would require to be acquainted with the leading facts of botany and zoology. In an elementary work of this kind, it would be out of place to enter largely into the characteristics of these sciences; but as a certain amount of knowledge is necessary to the understanding of subsequent details, we may shortly recapitulate the classification of plants and animals as generally received among botanists and zoologists.

120. VEGETABLES may be arranged under two grand divisions—CELLULAR and VASCULAR :—

I. *Cellular*—without regular vessels, but composed of fibres which sometimes cross and interlace each other. *Conferve*, lichens, fungi, *algæ* (sea-weeds), and mosses, belong to this division. In some of these families there are no apparent seed organs.

II. *Vascular*—with vessels which form organs of nutrition and reproduction. According to the arrangement of these organs, vascular plants have been divided into four classes :—1. Without perfect flowers, and with no visible seed organs (*cryptogamia*). To this class many fossil plants belong; such as gigantic tree ferns, horse tails, and others resembling ferns. 2. With flowers, but having the seeds naked (*phanerogamia gymnospermous*). To this class belong the cycadeæ, or pine apple tribe, and the coniferæ, or firs. 3. Flowering plants with one cotyledon or seed-lobe (*phanerogamia monocotyledonous*). This class comprises water-lilies, palms, lilies, the sedge, iris, and canes. 4. Flowering plants with two cotyledons (*phanerogamia dicotyledonous*). This class comprises all forest trees and shrubs. None of the families of plants, but those in this last class, have the true woody structure, or produce perfect wood, except the coniferæ, or firs; but the wood of these is easily distinguishable from true dicotyledonous wood.

121. ANIMALS, according to Cuvier, may be arranged into four great divisions—VERTEBRATED, MOLLUSCOUS, ARTICULATED, and RADIATED :—

I. *Vertebrated*—animals which have a skull containing the brain, and a spine or back-bone containing the principal trunk of the nervous system, commonly called the spinal marrow. They have red blood. This division comprehends the Mammalia (those animals which suckle their young), Birds, Reptiles, and Fishes.

II. *Molluscos*—animals in this division have no internal skeleton; the muscles are attached to the skin, which in many species is covered with a shell. The nervous system and viscera are composed of detached masses, united by nervous filaments. They have a complete system of

circulation, and particular organs for breathing by. Animals with Bivalve, Univalve, and Chambered shells, belong to this division; though many molluscs, like the common snail, have no shell.

III. *Articulated*—to this division belong Worms, Crustaceous animals like the lobster, and all Insects. Their nervous system consists of two long cords, ranging along the body, and swelling out in different parts into knots or ganglions. Worms having their bodies composed of rings are called annelides, and have red blood: some species of worms inhabit a calcareous tube, supposed to be formed by exudation.

IV. *Radiated*—comprises all those animals formerly called Zoophytes, or animal-plants, as corallines, &c. In animals of this division, the organs of sense and motion are circularly disposed around a centre or axis; hence the term radiated, or disposed in rays. They have no distinctly-marked nervous system, and the traces of circulation in many species can hardly be discerned. Many of the *radiata* are fixed, such as the corals; others move and float about, as the star-fish and sea-urchin.

122. *Besides the above distinctions*, which depend on the structure and form of plants and animals, there are others which should constantly be kept in view; namely, those depending upon mode of life, climate, and situation. The plants of the tropics are very unlike those of polar regions, both in number, size, and character; marine plants and animals are essentially different from those inhabiting fresh waters; and aquatic plants and amphibious animals present a very different appearance from those constantly existing upon dry land. Each race of plants and animals is, moreover, perfectly adapted for the functions it has to perform in the economy of nature; and is furnished with peculiar organs, according to the kind of food upon which it lives, and the other habits it displays. Thus, one set of organs indicates swiftness, another strength, a third prehensile or seizing powers, a fourth climbing, leaping, or swimming powers, a fifth that the animal lives on roots, on herbage, or on the flesh of others.

123. *As in the vegetable and animal economy of the present day, so in all times past*; and thus the geologist, by analogy and comparison, is able to decide as to the character of the fossil plants and animals which he discovers. He finds in their characters and skeletons a key to the modes of their existence, and can tell with precision whether they lived in the waters or on dry land, in fresh or in salt water, in a cold or in a hot climate; whether animals browsed upon plants or lived upon other animals, whether they are furnished with organs indicating an amphibious existence; and in general can determine their character and modes of existence. Moreover, as certain classes of plants and animals indicate certain conditions of the world, the geologist will be enabled by their remains to decipher the past history of our

globe, and so arrive at that which is the aim and object of all true geological research.

EXPLANATORY NOTE.

PETRIFACTIONS are, in general, described according to the mineral substance which enters most abundantly into their composition. If it be lime, then they are designated *calcareous* (Lat., *calx*, lime); if flint, *siliceous* or *silicified* (*silex*, flint); and so on of other minerals.

BITUMEN (Gr., *pitus*, the pitch tree)—a variety of inflammable mineral substances, which, like pitch, burn with flame in the open air. Naphtha, petroleum, and asphaltum, are familiar examples; and all substances impregnated with these bitumens are said to be *bituminous*. As mentioned in the text, it is the prevalent opinion that all bituminous matter is of organic or vegetable origin.

BITUMINOUS FERMENTATION.—All vegetable matter is liable to certain states of fermentation, according to the degree of heat, air, and moisture to which it is subjected. These states have been successively described as the *saccharine*, *vinous*, *acetous*, *septic*, and *bituminous*. For example, the *saccharine* is that which manifests itself in the operation of malting and in the ripening of fruits; if water and heat be applied, it passes into the *vinous*, or that by which wine and spirituous liquors are formed. Again, if, while the *vinous* is going on, air be partially admitted, the *acetous*, or vinegar-forming fermentation, will be produced; and by further exposure of the vegetable matter to the air, it will pass into a mass of earth and carbon: this fits it for the *septic*, or putrefying process; but if air be excluded, and heat, moisture, and pressure be present, the *bituminous* will be the result. By a knowledge of these processes, it is easy to understand how malt, wine, vinegar, vegetable mould, and coal, are respectively formed.

ADIPOCERE (Lat., *adeps*, fat, *cera*, wax)—a fatty substance produced by the decomposition of the flesh of animals in moist situations, or under water, resembling, in some of its properties, a mixture of fat and wax. It is found in damp grave-yards, in peat-bogs where animals have been accidentally entombed, and is also occasionally thrown up on the sea-shore after a storm. It has a chalky aspect, a soapy feel, is inflammable, and swims in water.

FOSSIL BOTANY AND ZOOLOGY.—The animals peculiar to a country constitute its *Fauna*, and the plants its *Flora*. The terms are respectively derived from the Latin *Fauni*, rural deities, and *Flora*, the goddess of flowers. As naturalists speak of the existing *Fauna* and *Flora* of any country, so geologists speak of the fossil *Fauna* and fossil *Flora* of certain geological epochs and formations.

CLASSIFICATION OF ROCK FORMATIONS.

124. *The subjects treated in the preceding sections may be regarded as introductory to the study of Descriptive Geology; for, without a knowledge of them, it would be impossible to comprehend the nature of the changes which our planet has hitherto undergone. Those changes are indicated by certain*

characters stamped upon the rocks which constitute its crust—characters obviously analogous to such as are now produced by causes in active operation around us. It was necessary, therefore, to learn something of the existing structure and conditions of the globe, and of the causes—mechanical, chemical, and vital—which are modifying these conditions, in order that we might be enabled to reason from what is recent and apparent, to that which has taken place at more remote periods.

125. *The term rock is applied by geologists* not only to those hard substances usually called so, but also to all sands, clays, gravels, and marls which occur in beds, strata, or masses. It is also used to denote a collection of such substances: thus, we say the “rocks of a country;” or, speaking more definitely of any mineral series, we say the Chalk rocks, the Carboniferous rocks, and so on. The rocks which compose the crust of the earth, though varying much in mineral character, as well as external appearance, occur either in masses, or in series having a close resemblance to each other; so much so, that geologists conclude that certain series have been formed under similar circumstances. This opinion is further confirmed by the fact, that certain series of strata always imbed fossils of a different character from those contained in any other series; hence the origin of rock classification.

126. *Leibnitz, in 1680, divided rocks into two great classes—*STRATIFIED and UNSTRATIFIED—the latter being the result of igneous fusion, and the former that of aqueous solution. This distinction, though of importance at the period to which we refer, was still of little avail in deciphering the history of the earth, as unstratified rocks are mingled with the highest as well as with the lowest strata; and as, moreover, the stratified rocks differ essentially from each other, and often contain very different fossil remains. Lehman, a German mineralogist, next proposed to divide the stratified rocks into—

PRIMITIVE—those containing no fossil organic remains.

SECONDARY—those containing remains of animals and vegetables.

LOCAL—those but partially occurring in different districts.

127. *Werner, the great German geologist, improved upon this classification,* and divided all rocks into Primary, Transition, Secondary, and Local. The term *Transition* was added by Werner, as implying that the rocks so called exhibited a passage from the primary into the secondary in regard to their mineral character, and also that the earth was changing from an uninhabitable to an inhabitable state during the period of their formation. Subsequently, from the fossil discoveries of Cuvier and others, a more definite idea was attached to the term Local, and the word *Tertiary* was

employed to denote all those regularly stratified beds which occur above the Chalk strata. These divisions—Primary, Transition, Secondary, and Tertiary—though liable to many objections, are still more or less in use by geologists; hence the following classification of the stratified rocks which compose the crust of the earth :—

FORMATIONS.	SUPERFICIAL ACCUMULATIONS—all loose and irregularly deposited masses of clay, sand, gravel, and boulder stones.
	TERTIARY—local deposits of regular strata, containing remains of plants and animals, not differing widely from those now inhabiting the globe.
	SECONDARY—strata of chalk, clay, and shale, red and white sandstones, coal, ironstone, and limestone—occurring in many parts of the world, and containing fossil plants and animals of different species from those now existing.
	TRANSITION—strata of sandstones, shales, slates, and limestones—containing few or no fossil plants, and the remains of no higher animals than crustacea, shell-fish, corals, and corallines.
	PRIMARY—slaty and crystalline strata, very hard and compact, and totally void of organic remains.

128. As geologists became better acquainted with the succession of the stratified rocks, a more minute subdivision took place, and these formations have been found to consist of systems, series, and groups of strata differing considerably from each other. Thus the term *formation* is applied to designate strata which seem to have been formed under nearly similar circumstances. A formation may consist of several *systems*—that is, strata having nearly the same mineral and fossil character; and there may be several *groups* in a system, such as a sandstone or limestone group. All these groups consist of *strata* which, according to their thickness or external appearance, are designated *beds*, *seams*, *layers*, *schists*, or *slates*. Bearing these terms in mind, the student will be prepared to understand the following table of stratified rocks as they occur in the British islands :—

TABLE OF BRITISH DEPOSITS.

SUPERFICIAL ACCUMULATIONS.	SOIL—decomposed vegetable and animal matter, with earthy admixtures.
	ALLUVIUM—deposits of sand, gravel, and clay, formed by the ordinary action of water.
	DILUVIUM—deposits of gravel and clay with boulders, formed by unusual operations of water.
TERTIARY.	CRAIG—calcareous conglomerate of marine shells and gravel; beds of marl.
	FRESH-WATER, OR ESTUARY BEDS—consisting of marls, imperfect limestones, and clays.
	MARINE BEDS—consisting of blue and plastic clays, thin beds of sand, lignite, &c.

SECONDARY FORMATION.	<i>Chalk System.</i>	CHALK—soft and white, with layers of flint ; chalk, hard, and without flints.	
		GAULT, or beds of bluish marly clays, with green sand.	
		GREEN-SAND—beds of green ferruginous sands, with chert nodules.	
	<i>Oolitic System.</i>	WEALDEN GROUP—beds of clay, argillaceous limestones, and sands.	
		OOHITE—beds of oolite limestone, calcareous grits, sands, and clays, all calcareous.	
		LIAS GROUP—bluish clays, alum shales, marls, and limestones, all finely stratified.	
	<i>New Red Sandstone, or Saliferous System.</i>	SALIFEROUS MARLS—variegated shales and shell limestone, with bands of sandstone.	
		RED SANDSTONE GROUP—fine-grained, sometimes conglomerate.	
		MAGNESIAN LIMESTONE—thick-bedded limestones and calcareous conglomerates.	
	<i>Carboniferous System.</i>	COAL MEASURES—alternating beds of coal, shale, ironstone, and sandstone.	
CARBONIFEROUS, OR MOUNTAIN LIMESTONE—thick-bedded grayish limestones and shales.			
CALCIFEROUS SANDSTONES—white, thick-bedded sandstones, and calcareous shales.			
<i>Old Red Sandstone System.</i>	YELLOW SANDSTONES, with beds of mottled shales and marls.		
	RED SANDSTONES—sometimes fine-grained, sometimes quartzose and conglomerate.		
	GRAY OR RUSTY-COLOURED SANDSTONES—micaceous, and often in flags or thin-bedded.		
TRANSITION.	<i>Silurian System.</i>	UPPER SILURIAN rocks—gray and bluish limestones, with coloured micaceous shales.	
		LOWER SILURIAN rocks—impure shelly limestone, mottled sandstones, dark calcareous flags.	
	<i>Grauwacke System.</i>	HARD ARGILLACEOUS rocks—thick-bedded sandstones, slaty sandstones, and limestones.	
		FINE AND COARSE-GRAINED slaty rocks—gray micaceous slates.	
	<i>Clay-Slate System.</i>	CLAY-SLATE—finely laminated ; dark, liver, and purplish-coloured.	
		HORNBLende AND CHIASTOLITE slates, finely laminated.	
	<i>Mica Schist System.</i>	CHLORITE SLATES—greenish-coloured slates, with mica, mica schist, talc schist, crystalline limestone, and quartz rock.	
		GNEISS ROCKS—intermingled with irregular beds of quartz rock, crystalline limestone, and mica schist.	
	PRIMARY.	<i>Gneiss System.</i>	

To assist the student in forming an idea of the succession of these formations and systems, the stratified rocks are more summarily arranged in the following diagram :—

	Vegetable Soil. Alluvial Clay, Sand, and Gravel. Diluvial Clay with Boulders.	
TERTIARY.	Sandstone and Calcareous Grits. Estuary Marls, Limestones, &c. Blue and Plastic Clays, Marls, &c.	
SECONDARY FORMATION.	Chalk Beds and Green-sand. Oolite Limestones and Grits. Lias Limestone and Shales. Saliferous Marls, Shell Limestone. New Red Sandstone. Magnesian Limestone. Coal Beds alternating with Sandstones, Clay-shale, Ironstone, and impure Limestones. Mountain Limestone.	
TRANSITION.	Old Red Sandstone. Silurian Limestones, &c. Grauwacke, Sandy Slates.	
PRIMARY.	Clay Slates. Mica and Talc Schists. Gneiss Rocks, &c.	
GRANITE.		

129. *The unstratified or igneous rocks occur in no regular succession*, but appear amidst the stratified without order or arrangement; heaving them out of their original horizontal positions, breaking up through them in volcanic masses, and sometimes overrunning them after the manner of liquid lava. From these circumstances, they are in general better known by their mineral composition than by their order of occurrence. Still, it may be convenient to divide them into three great classes; *granitic*, *trappean*, and *volcanic*—granitic being the basis of all known rocks, and occurring along with the primary and transition strata; the trappean of a darker and less crystalline structure than the granitic, and occurring along with the secondary and tertiary rocks; and the volcanic still less crystalline and compact, and of comparatively recent origin, or still in process of formation. Classifying the stratified and unstratified rocks after this idea, they would present the following tabular arrangement:—

<i>Unstratified.</i>	<i>Associated with,</i>
VOLCANIC.	{ SUPERFICIAL ACCUMULATIONS—soil, alluvium, diluvium.
	{ TERTIARY—crag, fresh-water marls, London and plastic clay.
TRAPPEAN.	{ SECONDARY—chalk, oolite, lias, new red sandstone, coal measures, mountain limestone, old red sandstone.
	{ TRANSITION—silurian and grauwacke rocks, concretionary limestones.
GRANITIC.	{ PRIMARY—clay-slate, crystalline limestone, mica schist, quartz, and gneiss rocks.

This division of the igneous unstratified rocks subserves many useful purposes in geology; at the same time that it is a distinction warranted by the nature, aggregation, and aspect of their component minerals. The *granitic*, so named from their distinctly granular and crystalline texture, comprise granite, syenite, protogine, primitive greenstone, serpentine, porphyritic, and other varieties of granite. The *trappean* (Swedish, "trappa," a stair) are so called from the step-like or terraced sides of the hills formed by these rocks, which include basalt, greenstone, clinkstone, claystone, trachyte, porphyry, and amygdaloid. The *volcanic*, as the name implies, are those products discharged by recent or active volcanoes, such as lava, obsidian, scorise, pumice, and tufa. As associated in the crust of the earth, the Unstratified and Stratified rocks would present something like the annexed section:—

SECTION OF EXISTING ARRANGEMENT OF ROCKS.



In the above section, the UNSTRATIFIED Rocks appear in hills and irregular disrupting masses, from the older granite to the active volcano; while the STRATIFIED occur in their regular order of succession. The *Primary* slope from the side of a lofty granitic mountain, at a high angle, and in bent or contorted strata; the *Transition* lie between the ranges of less elevated mountains; the *Secondary* occupy a still less elevated position, the Mountain Limestone being raised up on the hill-side, with the Coal Beds thrown into basin-shaped hollows, or broken up by faults, and the Magnesian Limestone and Chalk rising up into slight eminences; the *Tertiary*, in basin-shaped strata; and the *Superficial Accumulations* occur either as sandy downs by the sea-shore, or as diluvium, with boulders overlying the earlier formations. The student will perceive how the Tertiary strata are said to be above the Coal Measures, though they do not overlie them; and how the Coal Beds are above the Transition rocks, though removed from each other by a wide extent of country. The lowest strata being formed first, he will also understand why coal is said to be of more recent origin than clay-slate, and chalk younger than coal.

130. *It must not be supposed, however, that the stratified rocks always occur in any portion of the earth's crust in full and complete succession, as represented above; all that is meant is, that such would be their order if every group and formation were present. But whatever number of groups may be present, they never happen out of their regular order of succession; that is, clay-slate never occurs above coal, nor coal above chalk. Thus at London, tertiary strata occupy the surface; in Durham, magnesian limestone; in Fife, the coal measures; and in Perthshire, the old red-stone and clay-slate; so that it would be fruitless to dig for chalk in Durham, for magnesian limestone in Fife, or for coal in Perthshire. It would not be absurd, however, to dig for coal in Durham, because that mineral underlies the magnesian limestone; or for old red sandstone in Fife, because that formation might be naturally expected to occur under the coal strata of that county, in the regular order of succession. To make this order of succession still plainer, suppose the rock systems to be represented by series of figures, we might have—*

$$\left. \begin{array}{c} 7 \\ 6 \\ 5 \\ 4 \\ 3 \\ 2 \\ 1 \end{array} \right\} \text{ or } \left. \begin{array}{c} 7 \\ 6 \\ 5 \\ 3 \\ 1 \end{array} \right\} \text{ or } \left. \begin{array}{c} 7 \\ 5 \\ - \\ - \\ - \\ 3 \\ 2 \end{array} \right\} ; \text{ but we } \left. \begin{array}{c} 7 \\ 3 \\ - \\ 5 \\ - \\ 1 \\ 2 \end{array} \right\} \text{ or } \left. \begin{array}{c} 5 \\ 6 \\ - \\ 2 \\ 3 \\ - \\ 1 \end{array} \right\} \text{ or any such in-} \\ \text{never} \quad \text{find} \quad \text{version.}$$

Any member of the series may be absent; but those that remain never occur out of their natural order of *supraposition*.

EXPLANATORY NOTE.

CLASSIFICATION OF ROCKS.—Other “Systems of Classification” than the above have from time to time been advanced by geologists; but as most of them are founded upon some favourite theory, or upon mere local data, they have not met with anything like a general reception. It may be necessary, however, to notice some of the distinctions which occur in the works of certain modern authors. Conybeare and Phillips, in their *Geology of England and Wales*, divide the stratified crust into the following orders:—

1. *Superior*—containing the Tertiary deposits.
2. *Supermedial*—comprising the chalk, oolite, and new red sandstone.
3. *Medial*—comprising the coal measures, mountain limestone, and old red sandstone.
4. *Submedial*—containing the Transition strata.
5. *Inferior*—embracing all the Primitive formations.

Others have proposed to divide the crust into five great formations; namely, *Colluvial*, *Cretaceous*, *Carboniferous*, *Schistose*, and *Crystalline*; each of these formations being subdivided into three systems. Sub-

divided in this manner, the carboniferous and cretaceous would present the following arrangement :—

Supercretaceous—plastic clays, marls, and lignite beds (Tertiary).

Cretaceous—chalk, chalk marls, and green-sand.

Subcretaceous—weald, oolite, and lias strata.

Supercarboniferous—variegated marls, red sandstone, and magnesian limestone.

Carboniferous—coal measures, millstone grit, and mountain limestone.

Subcarboniferous—old red sandstone.

The rocks of the stratified crust, divided and subdivided in this manner, are easily remembered; the arrangement, moreover, being one which is warranted by actual observation. The term *fossiliferous* is commonly employed to denote all those formations in which fossils have been found; and *non-fossiliferous*, those, like the mica schist and gneiss, in which no organic remains have yet been discovered. *Metamorphic* is sometimes applied to those non-fossiliferous systems, implying that the strata have been so metamorphosed by heat, as to obliterate all traces of fossil exuviae. Mr Lyell divides the Tertiary strata into four groups; namely, *Eocene*, *Meiocene*, *Pleiocene*, and *Pleistocene*; these terms indicating the approach which the imbedded fossils make to existing nature. For example, *Eocene* (Gr., *eos*, the dawn, and *kainos*, recent), indicates those strata in which the dawn or commencement of recent animals takes place; *Meiocene* (*meion*, less), less recent; *Pleiocene* (*pleion*, more), more recent; and *Pleistocene* (*pleiston*, most), most recent, or approaching nearly to existing orders. Instead of Stratified and Unstratified, or Sedimentary and Igneous, some geologists make use of the terms *Neptunian* and *Plutonic*—the former being derived from *Neptune*, the god of the sea or water, and the latter from *Pluto*, the god of fire.

GRANITIC BASIS OF PRIMARY STRATA.

131. We commence our investigation of the earth's crust, by describing the lowest or earliest formations of strata. Some geologists in their descriptions begin at the surface, and proceed downwards; but it is certainly the more natural and intelligible method to commence with the lowest, and proceed upwards—seeing that the lowest have been deposited first, and that each succeeding formation must have been formed from the disintegrated materials of those which preceded it.

132. *Whatever may have been the origin of the globe, we are warranted in stating that GRANITIC ROCKS form a solid crust or basis upon which all the systems of strata rest.* These granitic rocks show no traces of stratification; they are all highly crystalline; none of their crystals are water-worn; and from these circumstances, as well as from the fact that we find them bursting up through, and displacing the primary strata, it is concluded that they are of igneous origin. If ever

this globe was in a fused state, as has been supposed by many philosophers, the granitic crust is such as would be formed by cooling down of the igneous matter. Cooling and contracting irregularly, it would assume an unequal surface; here forcing itself up into considerable heights, and there sinking into hollows; the highest granitic mountains bearing no greater proportion to the size of the globe, than the blisters and scoræ on a smelting furnace do to the liquid mass upon which they are formed.

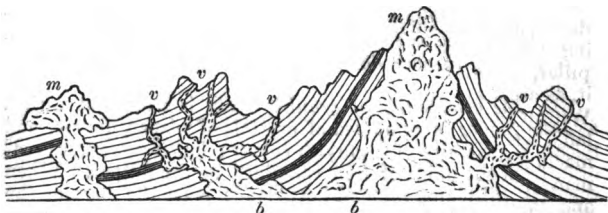
133. *The composition of granitic rocks is somewhat varied. Granite proper is composed of crystals of felspar, quartz, and mica; is generally of a grayish colour; but is sometimes reddish, from the oxide of iron contained in the felspar. When the dark glistening mineral hornblende takes the place of the mica, the rock is known by the name of Syenite, from Syene in Egypt, where it is found in great abundance; and when talc supplants the mica, the admixture of felspar, quartz, and talc, forms the Protogine of French geologists. Sometimes it is formed by an admixture of quartz and hypersthene, with scattered crystals of mica, and is then called hypersthenic granite; or it may assume a speckled and mottled appearance, from the presence of variously-coloured minerals, such as chlorite, and is then called serpentine, from the fanciful resemblance it bears to the serpent's skin. Porphyritic granite is also of common occurrence; that is, when, in addition to the crystals which compose the general mass, larger crystals of felspar are indiscriminately mingled through it. Occasionally, the minerals in granite are so arranged as to bear a resemblance to the lines in Arabic writing; hence this variety is known by the name of graphic granite.*

134. *Besides the above varieties, there are other distinctions in use among geologists, according to the colour and composition of granitic rocks. Felspar, quartz, mica, hornblende, and hypersthene, are the most abundant constituents; but the aspect of the mass is sometimes modified by the partial admixture of other minerals, especially actynolite, chlorite, talc, schorl, and steatite. When only two minerals form a granitic rock (as felspar and mica), it is called a binary granite; when three (felspar, quartz, and mica), a ternary granite; and when four (quartz, mica, felspar, and hornblende), a quaternary granite.*

135. *The structure of granite is always massive and irregular; its texture is of various degrees of fineness, from a hard and close-grained rock, to a coarse and loose aggregation of primary crystals.*

136. *The position and relation of granite to the primary*

strata is exceedingly irregular. Sometimes it rises up in mountain masses (*m m*), at other times spreads out as an undulating floor or basis (*b b*), and not unfrequently breaks through the unstratified rocks in veins (*v v v v*) of the



Relative Positions of Granite.

most fantastic description. From these facts, there can be no doubt of its igneous origin; and the student will therefore be prepared to find it, like all other igneous rocks, occurring amid the stratified formations at various periods of the earth's history. Generally speaking, it is associated with the primary and transition formations, just as trap rocks are usually associated with secondary and tertiary strata, or as volcanic products are mingled up with the superficial accumulations now in progress; but the student is not on this account to suppose that granite may not also be found in conjunction with secondary or tertiary strata.

137. *The geographical distribution of granitic rocks* is very general; they form many of the most extensive mountain ranges in the world. The Grampians in Scotland, the Cumberland and Cornwall hills in England, the Wicklow mountains in Ireland, the Alps in Switzerland, the Pyrenees in Spain, the Dofrafelds in Norway, the Abyssinian and other African ranges, and the Andes in South America, are all more or less composed of rocks partaking of a granitic character.

138. *The physical geography of a granitic district* is by no means remarkable for its fine scenery. Where the rock is soft, the hills have a heavy rounded appearance, and are only peaked and irregular in outline where it is hard, and flanked by stratified rocks. Forming, in general, very lofty hills and elevated table-lands, granitic districts present a bleak and barren landscape, which is rendered still more so by the snow-clad peaks of the loftier mountains.

139. *The economical uses to which granitic rocks and their*

products are applied are by no means unimportant. Compact granite, from its extreme hardness, is largely employed in the construction of docks, lighthouse foundations, bridges, and other structures where durability is the object in view. Waterloo Bridge in London, the Liverpool and other English docks, are built of Aberdeen granite. It is the ordinary building stone in the city of Aberdeen. The pyramids, Pompey's pillar, and other ancient Egyptian structures, are composed of it, as are also many monumental erections in our own country. Within these few years, the red granite of Peterhead, in Scotland, has been brought into use as an ornamental stone; and machinery has been erected to polish it like marble, to which many prefer it for chimney slabs, vases, pedestals, &c. Mica and talc are sometimes found in crystals more than a foot square; when of this size, they are split up into thin plates, and, from their transparency, used in some countries as a substitute for glass. Talc, by the Russians, is thought preferable to glass for ship light, as it is not apt to be broken by the firing of cannon; it also stands a higher degree of heat than glass without splintering. Some varieties of felspathic and talcose granites are easily decomposed by exposure to the atmosphere, and in this state produce a fine impalpable powder of silica and clay, of great use in the manufacture of porcelain, Mosaic tesserae, buttons, and artificial gems. The clay from decomposed felspar is known in China by the name of *kaolin*, and is used by that nation in the manufacture of their finest china. According to Dr Boase, upwards of 12,000 tons of decomposed felspar (*Cornish clay*) are annually exported from Cornwall to the English potteries.

EXPLANATORY NOTE.

GRANITIC GROUP.—To the many varieties of this group Mr Lyell applies the term *hypogene rocks* (Gr., *hypo*, under, and *ginomai*, I am formed); that is, nether, or under-formed rocks. This term he employs to avoid any theory as to the origin of granite; but it has not been generally adopted, the prevalent belief being, as mentioned above, that granite is of igneous origin; that it has resulted from the gradual cooling down of the globe while in an incandescent state; and that it therefore forms a basis for all the stratified systems.

GNEISS AND MICA SCHIST SYSTEMS.

140. Before describing the primary rocks, it is necessary to advert to a general fact, applicable to the character of all stratified formations. *Siliceous, argillaceous, calcareous, and*

carboniferous compounds, may be said to constitute the solid crust of the globe; and these compounds differ in their appearance and mode of aggregation according to the order of their occurrence. For instance, the siliceous rocks of the primary strata are compact and crystalline; in the secondary they are less compact, lose their crystalline appearance, and become sandstones of various degrees of fineness; in the tertiary they are often so soft in their texture as to be called sands; while in the superficial they are merely loose accumulations of sand and gravel. So it is with the argillaceous rocks—from the compact and glistening clay-slates of the primary, through the slaty shales of the secondary, and the laminated clays of the tertiary rocks, up to the soft plastic clays of our alluvial valleys. As with the siliceous and argillaceous, so with calcareous and carboniferous; hence a table may be formed exhibiting these gradations:—

<i>Siliceous.</i>	<i>Argillaceous.</i>	<i>Calcareous.</i>	<i>Carboniferous.</i>
Sand,	Alluvial Clay,	Marl,	Peat,
Sandstone,	Laminated Clay,	Chalk,	Lignite,
Grauwacke,	Slaty Shale,	Limestone,	Brown Coal,
Quartz Rock.	Clay-Slate.	Crystalline Marble.	Common Coal.

Thus, as we descend into the crust, the mineral ingredients of the stratified rocks assume different degrees of aggregation, gradually becoming harder and more compact, till ultimately they present a crystalline texture scarcely distinguishable from the granitic basis.

141. *The composition of the primary strata*, like that of the granite on which they rest, is often modified by the presence of peculiar minerals; though felspar, quartz, mica, talc, hornblende, and chlorite, constitute the greater portion of their mass. *Gneiss*, or the oldest system of stratified rocks, differs little from true granite in its mineral composition, except in as far as regards the aggregation of the simple minerals. In granite, the crystals of felspar, quartz, mica, and hornblende, are entire and distinct; in gneiss, their angles and faces are broken and water-worn. In granite, there are no traces of a laminated or stratified structure; in gneiss, this structure is evident, even where the strata are most indurated and contorted. All this attests the aqueous origin of gneiss—that it must have been deposited in water, and that it is composed of the disintegrated minerals of unstratified granite.

142. *The stratified structure which is sometimes confused and indistinct in gneiss*, is much more apparent and regular in mica schist. The particles of the latter are more water-worn,

and the abundance of fragmented mica gives its lamination a degree of parallelism not to be found in the former. Both, however, are frequently seen passing into each other, thus rendering it difficult to distinguish where the one system ends and the other begins. Passing over these dubious strata, the *mica schist system* is composed of alternations of mica schist, talcose schist, chlorite schist, hornblende schist, quartz rock, primitive or crystalline limestone, with occasional beds of clay-slate in the upper part of the system. Independently of their stratification, the mica schist rocks distinctly indicate, by their texture, that they have been formed by the action of water. The particles of which they are composed are more broken and rounded than those of gneiss—a circumstance arising from the fact, that they were partly derived from granite and partly from gneiss, which must thus have undergone a double process of attrition. The following engravings are intended to represent the external appearance of granite, gneiss, and mica schist—the first composed of distinct crystals, and showing no traces of lamination; the second irregularly laminated; and the third finely and regularly laminated.



Granite.



Gneiss.



Mica Schist.

143. *Gneiss and mica schist differ little from granite*, and still less from one another, in their mineral composition; showing clearly that it is chiefly in the degree of attrition which the original minerals have undergone, that their external differences consist :—

GRANITE—of felspar, quartz, and mica; felspar, quartz, hornblende; felspar and hornblende; or it may be of various combinations of these simple minerals.

GNEISS—of felspar, quartz, and mica; occasionally with hornblende and garnets in it.

MICA SCHIST—of mica and quartz, with hornblende and garnets contained in it.

TALCOSE SCHIST—of talc and quartz, and differs only in this respect from mica schist.

CHLORITE SCHIST—of chlorite and quartz.

HORNBLLENDE SCHIST—of quartz and hornblende, occasionally with actynolite.

QUARTZ ROCK generally contains hornblende or mica irregularly imbedded in it.

The particles of the primary strata are indefinite both as to size and arrangement—some are fine and close-grained, others

are conglomerate and coarse ; but all bear evident traces of their aqueous origin.

144. *There is nothing like a regular order of succession among the primary strata.* It may be stated generally, however, that gneiss underlies the mica schist ; that mica and other crystalline schists are the lowest in the system ; and that quartz rock, primitive limestone, and clay schist, make their appearance towards the upper part of the series. Stratification is sometimes obscure, and not very persistent ; that is, any one stratum is not found stretching over a great extent of country, as is the case with the secondary rocks. A seam of coal will often be found stretching over ten or twelve miles of country, without much difference either in quality or thickness ; but in the primary systems, the strata thicken, thin out, and disappear in a very capricious manner. In absence of anything like a characteristic section, the following rocks may be mentioned as constituting the great bulk of the primary formation :—Gneiss, mica schist, talc schist, chlorite schist, shorla-ceous schist, stea schist, hornblende schist, actynolite schist, quartz rock, crystalline limestone, hornstone, and protogine. Most of these rocks pass insensibly into each other, and thus many compounds are formed of which the student can only obtain a knowledge by the study of actual specimens.

145. *No organic remains have yet been discovered in the gneiss or mica schist systems ;* and if life, either in a vegetable or animal form, existed at the time these rocks were deposited, it must have been exceedingly rare, and confined to a few limited points on the earth's surface. (See note, p. 80.)

146. *As to the origin of the gneiss and mica schist systems, it is abundantly evident that the materials of which they are composed were derived from the underlying granite.* It has been stated that this rock forms a solid and irregular basis, on which all the sedimentary strata rest ; and if this be true, it is evident that its surface must have been partly under and partly above water, and subject to the degrading influence of atmospheric, aqueous, and chemical agencies. Moreover, if the granitic crust was formed by the cooling of an originally fused globe, the waters resting in the hollows must have been heated to a high degree, and the air must have been loaded with vapours. All this would further tend to hasten the degradation of the granite ; the runnels and streams would carry down the loose particles, laying down the heavier first, and carrying out the lighter and smaller to deeper water. In process of time the loose matter would get consolidated by the pressure of its own mass ; the high temperature then pervading the globe, together with chemical

agency, would assist in producing the crystalline texture ; and thus a variety of schistose rocks might be formed at one and the same time. That a high temperature existed during the formation of the primary rocks, we have ample evidence, not only in their hard and crystalline texture, and in the absence of all organic remains, but in the occurrence of certain minerals, such as garnet, whose presence denotes that the rocks in which it is found have experienced a degree of heat sufficiently high to form such a fusible mineral, but not enough to melt the other constituents of which they are composed.

147. *The igneous rocks associated with the gneiss and mica schist systems* are, as may be anticipated, the granitic on which they rest, and from which their materials have been directly derived. Sometimes the granite is in immediate contact with the gneiss, so much so, as to render it matter of difficulty to say where the one ends and the other begins ; at other times it touches the mica schist, or, it may be, passes through both in the form of dykes and veins. Later igneous rocks, such as porphyry, greenstone, and serpentine, are frequently found traversing the gneiss and mica schist in dykes and protruding masses ; and occasionally, still more recent effusions of trap are found passing through the primary strata, with their associated dykes and veins of granite. Metalliferous veins are not of frequent occurrence in the primary strata of the British isles, though they are found in those of central and northern Europe. Thermal springs are perhaps still more rare, though abundant enough in the gneiss and mica schists of other countries.

148. *The extent of country occupied by the primary strata* is very great, although as yet but imperfectly ascertained. They occur abundantly in the Highlands and islands of Scotland, in the north of Ireland, along the flanks of the Pyrenees, the Alps, the great mountain chains of northern Europe, in Asia, in Ceylon, in Africa, and in America, particularly in the Brazils and the United States.

149. *The physical aspect of primitive districts* is bold, rugged, and unfertile. Thrown into lofty mountains by the granite, and into abrupt and vertical positions, it is chiefly among gneiss and mica schist that those deep glens and abrupt precipices occur which give the well-known picturesque effect to Highland scenery. The student will readily perceive how this effect is produced, when he considers the hardness of the rocks, and the highly vertical and contorted positions into which they are thrown ; whereas in secondary formations, the position is in general flatter, and the strata

so soft, that they cannot present the same rugged and abrupt appearance.

150. *The minerals of commerce derived from these systems* are by no means numerous. Several of the metallic ores, such as tin and copper, occur in veins traversing these strata. The limestones, from their highly crystalline texture, in general produce valuable marbles; but none of the other rocks are of use for architectural purposes. Potstone, or the *lapis ollaris* of the ancients, of which very pretty jars and vases are manufactured, is found in stea schist. Amianthus, or flexible asbestos, occurs among the mica schists, and is sometimes used in the manufacture of fabrics which are indestructible by fire. The garnet is a well-known precious stone; and many of the most valuable are found in the rocks of this system.

151. *It may be stated generally of gneiss and mica schist*, that they are the oldest sedimentary rocks, and rest upon masses which owe their origin to heat; that they are totally different from other stratified rocks, inasmuch as their particles have not undergone so much attrition, and likewise as they have been subjected to a higher degree of heat; that they are destitute of organic remains, and therefore afford no evidence of habitable dry land; and lastly, that they are spread over so great an extent, as to be considered almost universal.

EXPLANATORY NOTE.

SILICEOUS (Lat., *silex*, flint)—all rocks having a flinty texture are said to be siliceous. Quartz is the purest form in which *silex* occurs. When grains of quartz are loosely aggregated, as in some sandstones, the rocks are said to be *quartzose*, or gritty.

ARGILLACEOUS (Lat., *argilla*, clay)—rocks composed of clay, or having a considerable portion of clay in their composition, are said to be argillaceous.

CALCAREOUS (Lat., *calx*, lime)—composed of, or containing a considerable portion of lime.

CARBONIFEROUS (Lat., *carbo*, coal, or charcoal)—rocks containing coal, or associated with coal, are said to be carboniferous. *Carbonaceous* is applied when traces of carbon appear intermingled with their texture.

SCHIST (Gr., *schisma*, a splitting or division)—applied to rocks easily split up into slaty-like plates or divisions, as mica schist.

GNEISS AND MICA SCHIST.—It has been already stated, that to these systems Mr Lyell applies the term *metamorphic*, meaning thereby that they have undergone a metamorphosis, or change, in their sedimentary character, so as frequently to be mistaken for true igneous or granitic rocks. According to this opinion, gneiss and mica schist may have contained organic remains, the traces of which have since been obliterated by heat; even granite itself may be a highly metamorphic.

CLAY words, that it may be altered or metamorphosed sedimentary rock—in continuous history of the globe from its origin upwards—become strata and their remains being thus successively obliterated. The theory, however, has not been generally adopted, and, from the evidences which most strata afford of their formation, it is not to be so.

CLAY-SLATE, GRAUWACKE, AND SILURIAN SYSTEMS.

152. It has been stated that the four great types of all stratified rocks are siliceous, argillaceous, calcareous, and carboniferous; and that, in general, each system is characterised by some prevailing type. The gneiss and mica schists have been described as eminently *siliceous*: we shall now learn that in the clay-slate, grauwacke, and silurian systems, *argillaceous* compounds prevail—almost wholly so in the first system, mingled with arenaceous strata in the second, and with calcareous and arenaceous beds in the third.

153. *The clay-slate system* presents a vast thickness of fine-grained fissile argillaceous rock, of considerable hardness, varying in colour, and of glistening aspect. The prevalent colours of slate are black, green, bluish, purplish, and mottled; some varieties being hard and splintery, others soft and perishable. The character of any particular slate is, however, very persistent; the accidental or imbedded minerals are few—these being chiefly cubic-iron pyrites, and crystals of chialstolite and hornblende.

154. *The composition of the grauwacke* is much more varied and irregular. As sandstone may be said to be consolidated sand, and conglomerate consolidated gravel, so may grauwacke be defined to be an aggregate of clay, grains of quartz, felspar, and mica, with fragments of jasper and other minerals. The cementing material is clay, which often constitutes the greater portion of the rock, and in such cases the texture differs little from that of clay-slate; but in many strata fragmentary ingredients prevail, so that the texture varies in fineness from that of a coarse slate to a conglomerate of pebbles more than an inch in diameter. Like clay-slate, grauwacke presents various degrees of hardness, though, generally speaking, it may be described as a highly indurated conglomerate—indicating most clearly its origin from the waste of earlier siliceous and argillaceous formations. Associated with the slates and grauwackes are occasional beds of concretionary limestone, which partake of the

argillaceous character of the rocks with which they are associated.

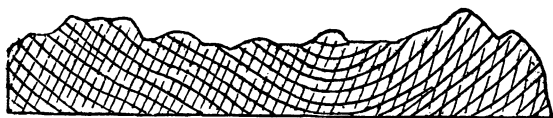
155. *In the silurian system*, limestones occur more frequently, so that the calcareous type, or, at all events, an intimate blending of argillaceous and calcareous compounds, may be said to prevail. Until a recent period, this system was considered as a portion of the grauwacke group, and as marking its passage into the gray micaceous beds of the old red sandstone. Merely looking at cabinet specimens, it would be impossible to distinguish between many of the grauwacke and silurian rocks, but taking them in the mass, they are readily distinguishable. In the first place, their sedimentary character is very marked; they present more rapid alternations from one kind of strata to another; they have undergone fewer changes by heat; and are generally looser and more earthy in their texture. The limestones are less crystalline than those of the early grauwackes; the arenaceous beds are also less siliceous, and more closely resemble ordinary sandstones, while the abundance of organic remains justifies their arrangement into a separate system.

156. *From this description of these systems*, it will be seen that their main type is argillaceous; eminently so in the clay-slates; abundantly enough in the grauwackes, which pass, in texture, from slate to a coarse quartzose conglomerate; and perceptibly in the silurian limestones, which are all of a dark argillaceous character. It is also worthy of notice, that the crystalline aspect which characterised the Primary Rocks disappears with the clay-slates, and gradually passes into an earthy or arenaceous texture in the grauwacke and silurian. It is true that some of the lower slates have a glistening semi-crystalline appearance; but, taken in the mass, and in conjunction with the grauwacke and silurian rocks, the whole materials of these systems are more loosely arranged, and more decidedly sedimentary, than the gneiss and mica schists. The term *Transition* has been applied to the series, as not only indicating a change in the causes of formation, but implying that the world was then passing from an uninhabitable to an inhabitable state.

157. *The stratified structure is abundantly obvious in the rocks of the transition series.* The occurrence of interstratified limestones, and the bands of different colour and hardness in the slates, all point to deposition in water; while the succession of fine and coarse-grained grauwackes, of silurian limestones and shales, is as decisive of stratification as alternations of sandstone, shale, and coal. From this statement, the student must not, however, expect to find the sedimentary struc-

ture very distinctly marked in the clay-slates; it is only in the grauwacke and silurian that this is decided. *Lamination* may be said to prevail in the rocks of fine texture, and *stratification* in those of an arenaceous or calcareous character. The laminated structure of grauwacke is, however, of a different character from lamination in clay-slate; in the former it is the result of deposition, in the latter it is the effect of a subsequent change which the rock has undergone, called *cleavage*.

158. *Cleavage* differs from ordinary lamination in this respect, that it causes clay-slate to split up into thin plates at right angles, or nearly so, to the bed of stratification; while lamination simply implies that any stratum can be split up into a number of thinner layers or laminae. Cleavage occurs in several varieties of rock, but it is most regular and distinct in clay-slate; and it is owing to this structure that the rock has the property of being split up into thin divisions for roofing and other purposes. The appearance which cleavage presents in the mass is represented beneath, by the nearly perpendicular lines cutting those of stratification at a high angle. How



Section Exhibiting Lines of Cleavage.

cleavage has been produced, is still an undecided problem among geologists; though it may be stated generally, that it seems to have taken place long after the deposition of the strata in which it occurs, and, like crystallisation, to owe its origin to the influence either of heat or of electricity, or perhaps to both. (See note.)

159. *The succession of strata in the clay-slate, grauwacke, and silurian systems*, has not yet been very clearly ascertained. In general terms, it may be stated that the lower slates partake of a micaceous or hornblendic character; that they become less crystalline as we ascend in the series, and are succeeded by finely-laminated grauwacke, with interstratified limestones. In the grauwacke there is no apparent order of succession, although, in most localities, limestones and argillaceous beds prevail in the lower, and grits and conglomerates in the upper portion of the system. In the silurian, order is still less obvious; but, on closer study, it is found that grits and grauwacke-looking rocks prevail in the lower portion of the system, dark-coloured shales and limestones in the middle, and slaty micaceous sandstones in the upper. The fol-

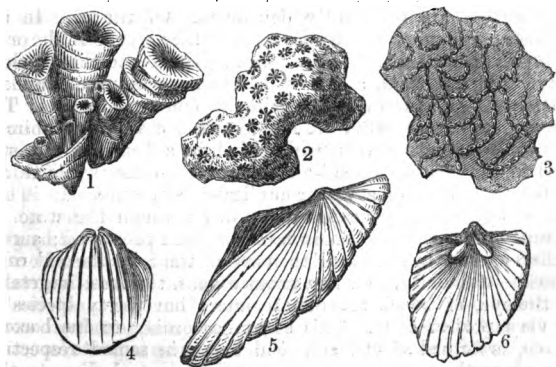
lowing detailed section will convey to the student a more correct idea of the order and succession among these systems :—

- | | | |
|-------------|---|--|
| SILURIAN. | { | 1. Slightly micaceous thin-bedded sandstones.
2. Gray and blue argillaceous limestones.
3. Liver-coloured shale, with concretions of earthy limestone.
4. Highly concretionary subcrystalline blue and gray limestone.
5. Dark-gray argillaceous shale, with nodules of earthy limestone.
6. Thin-bedded impure limestone, containing shells, alternating with finely-laminated micaceous sandstone of a greenish colour. |
| GRAU-WACKE. | { | 7. Sandstones, grits, and limestones ; arenaceous beds prevailing.
8. Dark-coloured flags, chiefly calcareous ; sandstones and sandy schists.
9. Grauwacke slates and sandstones, coarse limestones, and thick-bedded grauwacke rocks.
10. Dark argillaceous limestone, with shells and corals.
11. Peculiar slaty and flaggy beds : mottled in colour ; sometimes coarse and conglomerate, generally of moderate fineness, alternating with coloured clayey beds. |
| CLAY-SLATE. | { | 12. An immense thickness of clay-slate of various colours—blue, black, greenish, purple, or mottled ; of fine grain, sometimes compact, sometimes soft and useless. |

160. *The organic remains of these systems* are possessed of more than ordinary interest, from the fact of their being the earliest forms of life with which we are acquainted. In the preceding systems we have no traces either of vegetable or of animal existence : life begins to dawn only with the development of the clay-slate group, and to become more abundant as the deposition of the grauwacke and silurian proceeds. The earliest forms of vitality are not plants, but animals—animals undoubtedly low in the scale of organised being, but still perfect animals, as perfectly adapted to the condition of things under which they had to live as those now existing. They are wholly *marine* ; and here it may be observed, that no remains of *terrestrial* animals have yet been discovered by geologists earlier than towards the close of the Secondary Formations. In the clay-slate and grauwacke, no traces of vegetable organism have been found, and only about thirty species of corals and shell-fish ; in the silurian, animal remains become much more abundant ; but doubt is entertained respecting some fragments of sea-weeds and ferns said to belong to this formation. Whether the remains of plants and animals were entombed in these earlier formations, and have since been

obliterated by the agency of heat, geological science has not been able to determine; but at present, we are warranted in stating, that only a few rare corals and shells occur in the clay-slate system; a greater number of corals, shells, and crustacea in the grauwacke; and a variety of corals, shells, crustacea, fish bones, and teeth, in the silurian. So far as they have been examined, all these remains belong to species long since extinct; indeed, are distinct from those which occur in the Secondary Strata, and bear only a generic resemblance (often a faint one) to existing races.

161. *From the scantiness and peculiarity of organic life, it is difficult to arrive at any conclusion as to the condition of the world at this early period.* The existence of shell-fish would seem to indicate the co-existence of marine plants upon which they fed; and though we are aware that molluscous animals might prey upon each other, still, the probability is, that marine vegetation was to some extent spread over the bottom of the transition seas. The preponderance of coral-like animals points to a warm and favourable condition of the waters for their development; and it may be that this highly heated condition entirely prevented the growth of terrestrial plants, and rendered even those of marine growth of so rare occurrence. Be this as it may, we are only certain of several species of *Zoophytes*, *Mollusca*, and *Crustacea* in the clay-slate and grauwacke rocks—among which the most characteristic are those exhibited in the following group:—

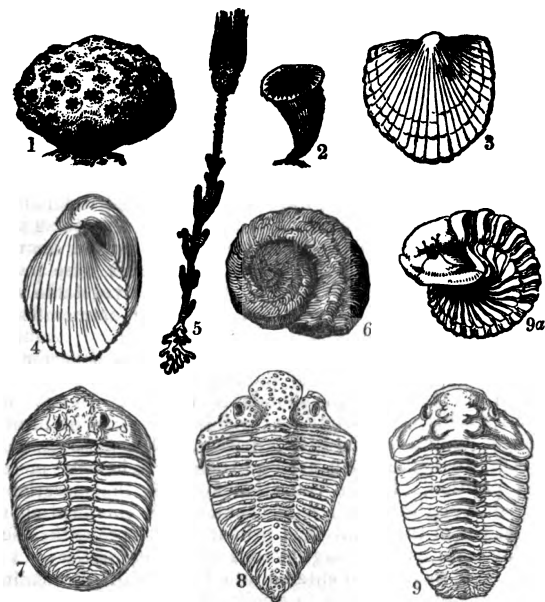


1. *Cyathophyllum Cyathus*; 2. *Heliopora Porosa*; 3. *Catenipora Labyrinthica*;
4. *Producta*; 5. *Spirifera*; 6. *Terebratula*.

162. *The fossils of the silurian system* are much more abundant; there are a greater number of species belonging to each genus; annulosa, crustacea, and fishes, are decided; and, according to many geologists, plants allied to the algae (sea-weeds), the equisetacea (horse-tails), filices (ferns), and others, make their appearance. Passing over the remains of plants and true vertebrated fishes, about the existence of which at this period there is still great obscurity, we shall notice some of the ascertained peculiarities of the radiata, mollusca, and articulata belonging to the Transition era.

163. *The waters of the silurian period* seem to have been crowded in some localities with zoophytes and corals, for certain limestones are as much composed of their remains as a coral reef is of recent corals. Among the radiata, the *crinoid* or *encrinite* family occur for the first time, these differing from other corals (see par. 300) in the self-dependent nature of their structure, their fixed articulated stalk, and floating stomach furnished with movable rays for the seizure and retention of their food. The shell-fish also become more numerous and distinct in form; *spirifera*, *terebratulæ*, and *productæ*, are every where abundant: and *chambered shells*, like the existing nautilus, begin to people the waters. It must be remarked, however, that the encrinites and chambered shells of this early period are not so numerous, so gigantic, or so perfect in their forms, as those of the Secondary Strata; it is in the mountain limestone group that the crinoidea attain their meridian, and in the lias and oolite that the *ammonites* and *nautili* are most fully developed. Of the crustacea of this era, the most interesting and abundant type is the *trilobite* (three-lobed), of which several genera and many species have been described, and to which scarcely any existing creature bears an analogy. The trilobite (see 7, 8, 9 in the following engraving) was a true crustacean, covered with shelly plates, terminating variously behind in a flexible extremity, and furnished with a head-piece composed of larger plates, and fitted with eyes of a very complicated structure. It is supposed by some to have made its way through the water by means of soft paddles, which have not been preserved; and by others merely to have sculled itself forward by the aid of its flexible extremity. Of its various organs, the most interesting is the eye, of which several specimens have been obtained in a very perfect state. This organ, according to fossil anatomists, is formed of 400 spherical lenses in separate compartments, on the surface of a cornea projecting conically upwards, so that the animal, in its usual place at the bottom of waters, could see everything around. As there are two eyes. one of

the sides of each would have been useless, as it could only look across to meet the vision of the other; but on the inner sides there are no lenses, that nothing may, in accordance with a principle observable throughout nature, be thrown away. It is found that in the *serolis*, a surviving kindred genus, the eyes are constructed on exactly the same principle, except that they are not so high—a necessary difference, as



1. *Astrea*; 2. *Turbinolia Fungites*; 3. *Terebratula Rieca*; 4. *Leptæna Lata*; 5. *Actinocrinites*; 6. *Euomphalus Rugosus*; 7. *Asaphus de Buchii*; 8. *Asaphus Tuberculatus*; 9. *Calymene Blumenbachii*; 9a. Side view of *Calymene* while rolled up.

the back of the *serolis* is lower, and presents less obstruction to the creature's vision. This little organ of a trivial little animal carries to living man the certain knowledge that, many ages ago, the air he breathes, and the light by which he sees, were the same as at this hour, and that the sea must have been in general as pure as it is now. If the water had been constantly turbid or 'chaotic, a creature des-

tined to live at the bottom of the sea would have had no use for such delicate visual organs. "With regard to the atmosphere," says Dr Buckland, "we infer that, had it differed materially from its actual condition, it might have so far affected the rays of light, that a corresponding difference from the eyes of existing crustaceans would have been found in the organs on which the impressions of such rays were then received. Regarding light itself also, we learn, from the resemblance of these most ancient organisations to existing eyes, that the mutual relations of light to the eye, and of the eye to light, were the same at the time when crustaceans endowed with the faculty of vision were placed at the bottom of the primeval seas, as at the present moment."

164. *The animals of this early period, like those now existing, were partly herbivorous (living on plants), and partly carnivorous (living on the flesh of others).* The polypes and crinoidea, it is true, merely secreted limy matter from the waters of the ocean wherewith to build their calcareous structures; but while certain tribes of shell-fish were living on the sea-weeds which flourished along the shores, other races were preying upon these, or upon each other. Among the vegetable eaters were the productæ, terebratulæ, &c.; the ammonites and trilobites were those which lived upon others.

165. *That the transition strata have been derived partly from the disintegrated materials of the gneiss and mica schists, and partly from the granite, is abundantly obvious.* In the gneiss and mica schists, the primitive crystals of the granite in many instances had undergone little attrition, and in most cases only sufficient to make them arrange themselves in a flat or laminated position. In the transition systems, the material has suffered sometimes both a mechanical and chemical change. The felspar of the granite and primary strata presents itself in the clay-slate as a soft argillaceous sediment, destitute of the potash and soda which entered into its crystallised condition. The quartz presents itself in sandy grains, without any particular form, sometimes finely pulverised, at other times coarse and gritty. The mica is variously disseminated, scarcely appearing in some strata of the grauwacke; but occurring in others of the silurian, so as to give them a micaceous and laminated aspect. All this implies the combined agency of air and water—the atmosphere to assist in the chemical decomposition of the felspar, water to transport it to the sea of deposit. The fineness and thickness of the clay-slate deposit indicates an immense depth of still-water; the sandy and conglomerate beds of the grauwacke not only the action of rivers, but the action of the sea upon its shores; while the calcareous beds of

the silurian implies the agency of the coral animal, precisely similar to that now going forward in the Pacific. Here, then, we have a condition of the world with hills and valleys, rivers and seas—the atmospheric agents acting upon the cliffs and precipices; the aqueous also degrading the rocks, transporting the material, and depositing it along the shores of seas, whose waters gave birth to corals, shell-fish, and fishes. Fine clayey silt formed clay-slate; sand and other mud slaty sandstones; gravel grauwacke conglomerate; and coral polypes beds and reefs of limestone. We have no evidence of terrestrial life; and the necessary inference is, that the conditions of the world did not then permit of its being called into existence.

166. *The igneous rocks associated with the transition series* are granite, serpentine, porphyry, greenstone, varieties of trap, and mineral veins. Indeed there is scarcely a development of the clay-slate or grauwacke systems without associated granitic rocks; and the greater portion of the silurian strata are thrown into inclined and contorted positions by the same agency, while effusions of trap make their appearance among the latter strata. Perhaps the most extensive and gigantic efforts of volcanic power were exhibited at the close of this period; and there is abundant proof that all the principal mountain chains in the world were then upheaved. The Grampian and Welch ranges, the Pyrenees, Hartz mountains, Dofrafelds, Uralian, Himmaleh, Atlas range, Mountains of the Moon, and other African ridges, the Andes, and Alleghanies, all seem to have received their present elevation at the close of the transition period. From this fact, the student will more readily perceive how the primary and transition strata should be thrown into highly inclined and contorted positions; how they should be traversed by so many dykes and mineral veins; and how slaty cleavage, and other alterations by heat, should have taken place.

167. *The extent of country over which the clay-slate, grau-wacke, and silurian systems are spread*, must be sufficiently indicated by the mention of the principal mountain ranges in the world, from whose sides and flanks their strata slope away for many leagues on either side.

168. *The geographical features of transition districts* are bold and mountainous, and are well illustrated by the characteristic scenery of Wales, the Cumberland Lakes, and the Scottish Highlands. "Supported by granite," says Professor Phillips, "and mixed with igneous masses, the slaty rocks of the English lakes rise to more than 3000 feet in height, and present a variety of outline, and intricacy of combination,

which, in connexion with clear lakes and considerable waterfalls, leave to Switzerland little superiority." This grandeur, intricacy, and variety of aspect can be readily accounted for, when we consider the height to which these strata have been elevated, the vertical positions into which they are thrown, and the irregularity of their composition, which allows them to be scooped out and worn down to a thousand forms—here craggy and splintery, there sinking, or rather cleft into fearful gorges and ravines.

169. *The economic uses* to which the minerals of these systems are applied are numerous and important. From the clay-slate are derived roofing-slate, writing-slate, and a variety of slates for ornamental and other purposes. Flagstones and pavement are obtained from the grauwacke and silurian beds, and several ornamental marbles from the limestone of the same systems. But the mere rock minerals are of little value in comparison with the metallic veins found in these strata. Tin, lead, copper, silver, gold, and other metals, are found abundantly in the veins which traverse the clay-slate; indeed they form in Britain, as well as in other countries, the principal metalliferous rocks, with the exception of the lead and ironstone, of the carboniferous system.

EXPLANATORY NOTE.

GRAUWACKE—a German miner's term, signifying *gray rock*; adopted in geology to designate the grayish slates and siliceous conglomerates of the transition strata. English geologists have conferred upon this group the name of *Cambrian*, from its forming a large portion of the surface of Cambria or Wales; the term grauwacke is more general and descriptive.

SILURIAN—a term invented by Mr Murchison to designate those calcareous and argillaceous beds which lie between the grauwacke and old red sandstone. The word is derived from *Silures*, the name of an ancient tribe who inhabited that district of country between England and Wales where these rocks are very clearly developed.

PYRITES—a mineral composed of sulphur and iron—*sulphuret of iron*. It is usually of a brass-yellow colour, brilliant, and crystallised. Those little shining crystals so abundant in some kinds of roofing-slate are cubic pyrites. The name is derived from the Greek, *pyr*, fire; because the mineral occasionally produces spontaneous combustion.

LAMINATION (Lat., *lamina*, a leaf or blade)—applied to thin layers or leaf-like divisions of rocks.

ARENACEOUS (Lat., *arena*, sand)—sandy. Rocks chiefly composed of sand are described as arenaceous. The principal constituent of sand is quartz or siliceous; and the terms *siliceous*, *quartzose*, and *arenaceous*, are applied to rocks according to the appearance which their textures present. Thus, highly indurated and close-grained sandstone is said to be siliceous; if the particles of quartz be large and distinct, quartzose; and if moderately fine, and rather loose in texture, arenaceous.

GRITS—hard sandstone, in which the grains of quartz are sharp and angular, are technically called *grits*, as millstone-grit, grindstone-grit, &c.

CLEAVAGE.—The peculiarities of this structure have given rise to many speculations and experiments. Mr R. W. Fox submitted a mass of moist clay, worked up with acidulated water, to a weak electric action for several months ; and it was found at the end of that time to present traces of cleavage, the laminae being at right angles to the electric forces. Others are of opinion that cleavage is superinduced, when considerable chemical action takes place in any finely pulverised substance as clay—cleavage being thus regarded as a species of rude crystallisation. Another class of theorists, from observing that slaty cleavage occurs among the shales of the coal measures, when these are in the neighbourhood of igneous rocks, attribute the structure to heat. It is not unlikely that all these causes may have been concerned in producing cleavage ; for, when better understood, it is more than probable that heat, electricity, and chemical action, are only modifications of one universal agency.

OLD RED SANDSTONE SYSTEM.

170. Until a comparatively recent period, geologists were accustomed to consider gneiss, mica schist, clay-slate, and old red sandstone, as sufficiently distinctive of all the stratified systems which lay underneath the coal measures. We have seen, however, that, in point of mineral composition, as well as in organic remains, the clay-slate differs essentially from the grauwacke ; and that grauwacke, as we ascend, begins to lose its arenaceous character, and to be succeeded by a series of argillaceous and calcareous beds more prolific in fossils, and in the mass perceptibly different. To this series of strata Mr Murchison applied the term *Silurian system*—a system which may be said to partake of the character of the grauwacke beds beneath, as it insensibly passes into the gray micaceous flagstones of the old red sandstone above. The student must not, however, suppose that all these systems are to be met with fully developed in every country ; all that the science of geology affirms is, that, when they are present, the above is their order of occurrence, and the general aspect and character they assume. Sometimes, indeed, the clay-slate is represented by a few indistinct argillaceous beds ; and in many places it is difficult to discover anything like a well-defined series of strata corresponding to the silurian rocks of Mr Murchison ; but, generally speaking, there is always some shade of distinction, either in mineral or fossil character, which enables us to trace the gradation of these successive systems. Whatever difficulty may be experienced in ascertaining the presence and limits of the grauwacke and silurian systems, there is seldom any doubt as to the old red sandstone, which, in the British islands, is one of the most clearly developed of rock formations.

171. *The composition of the old red sandstone*, as indicated by the name, is chiefly arenaceous, presenting a succession of sandstones alternating with subordinate layers of sandy shale. The sandstones pass, in fineness, from close-grained fissile flags to thick beds of conglomerate, the latter being composed of pebbles from the size of a hazel-nut to that of a man's head. The whole system is tinged with the peroxide of iron, the colours ranging from a dark rusty gray to brick-red, and from a mottled purple and fawn shade to a cream-yellow. The mottled aspect is principally found in the shales which, from their sandy character, may be regarded as imperfect sandstones. There are also some calcareous beds in the system; but these are not regularly developed, and are all siliceous and concretionary in their composition and texture. From their impure and concretionary aspect, they are generally known by the name of *cornstones*, and are of little or no use as limestones. Taken in the mass, the composition of this system is sufficiently indicated by the term *old red sandstone*—the epithet “old” being applied to distinguish it from another series of red sandstones which occurs above the coal measures, and is usually designated the *new red sandstone*.

172. *The order of succession among the old red sandstone strata* varies considerably in different localities. It has been stated that the prevailing mineral characters are—fine-grained red sandstones, including detached pebbles; beds of coarse conglomerate; fine-grained fissile micaceous beds of a gray colour, locally called *tilestones* and *flagstones*; layers of mottled shales; and strata of yellow sandstone. Now, although in some districts the conglomerate may be undermost, and in others the tilestones, yet, making allowance for these local deviations, the following may be taken as the most frequent order of occurrence :—

COAL MEASURES.

OLD RED SANDSTONE SYSTEM.

1. Yellow sandstones, fine-grained, including detached pebbles, and alternating with layers of mottled shale. Remains of fishes, but no traces of vegetables.
2. Red conglomerate, or Puddingstone, of vast thickness, either in one mass, or interrupted by occasional beds of red sandstone. No organic remains.
3. The red sandstone proper, generally in thick beds of a brick-red colour, enclosing detached pebbles of quartz and other primary rocks. Conglomerate beds and concretionary limestones are occasionally interstratified. Organic remains rare, and not very distinct.
4. Gray micaceous beds, sometimes dark and bituminous. These vary in thickness, from one inch to several feet. Remains of fishes abundant; some vegetable impressions.

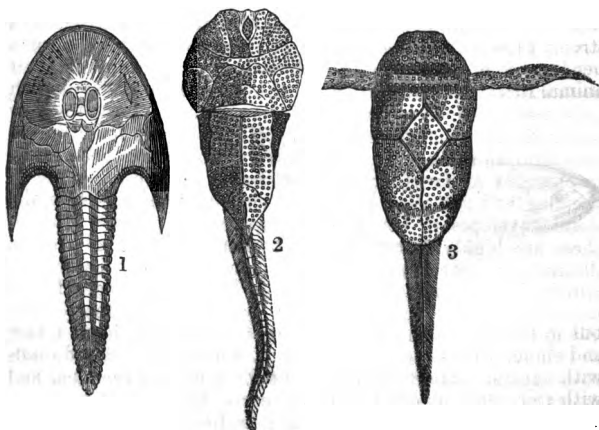
GRAUWACKE.

The preceding synopsis represents the usual order of the system as it occurs in Scotland. All of these groups are well marked in the field ; and when treated not as distinct systems, but as portions of one great system, materially aid the investigations of the geologist.

173. *The organic remains of the system*, if not so numerous as those of the grauwacke beneath, or the carboniferous measures above, are at least equally interesting, on account of their peculiarities and adaptation to the conditions under which they were destined to exist. The remains of plants are few and indistinct ; but are apparently allied to those found in the true silurian rocks. In the tilestone group have been found impressions of ferns, equisetaceæ, leaves resembling those of the flag and flowering rush, and circular markings like the floral envelopes or berries of some shrubby plant. Most of these are highly carbonised and broken, as if drifted from a distance by water, and deposited among the sandy material in which they are now imbedded. A few carbonaceous layers occur among the schistose beds ; but vegetable matter nowhere abounds in sufficient quantity to form bituminous layers or thin seams of coal. Taken as a whole, the old red sandstone system is particularly barren of vegetable remains, and seems to evince a condition of the earth which did not permit of the growth of plants unless in detached and limited areas ; these plants being by no means high in the scale of vegetable organisation. Its animal remains are more abundant and distinct ; but present little variety—the prevailing types being marine fishes of simple but curious structure.

174. *The fossil fishes, or ichthyolites, of the old red sandstone*, present the first distinct trace of the existence of the highest division of the animal kingdom ; namely, *vertebrata*. It must be remarked, however, that the earliest genera are not of the most perfect structure ; but form, as it were, a link between the humbler crustacea and fully-developed fishes. The *cephalaspis*, *coccosteus*, and *ptericthys*, represented in the following engraving, are the most prominent types of these crustacean-like families. The *cephalaspis*, in general figure, resembles the *asaphus* of the silurian rocks, is covered with bony plates, and takes its name from the buckler-shape of its head (Gr., *kephale*, the head, and *aspis*, a buckler). The *coccosteus* is also enveloped in a bony covering, is furnished with a tail for locomotion, and takes its name from the berry-like tubercles which dot its plates (Gr., *kokkos*, a berry, and *osteon*, a bone). The *ptericthys* has the same kind of covering or external skeleton ; but its distinguishing feature is a pair of wing-like appendages, which seem not only to have aided

in locomotion, but to have reared defensively when attacked. It takes its name from these appendages (Gr., *pteron*, a wing, and *ichthys*, a fish), and is one of the most abundant fossils in this formation—being as characteristic of the old red sandstone

1. *Cephalaspis*.2. *Coccoecosteus*.3. *Pteriothys*.

as the trilobite was of the silurian rocks. In the *holoptychius* (figured below), and some others, this bony covering prevails; but it is formed of a greater number of plates finely enameled and curiously engraved, while the general outline of the

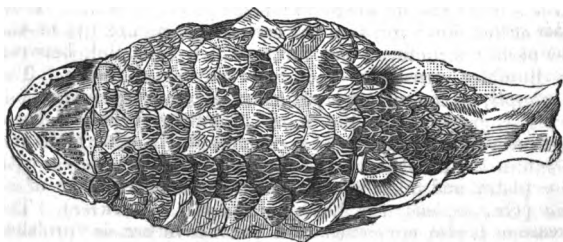
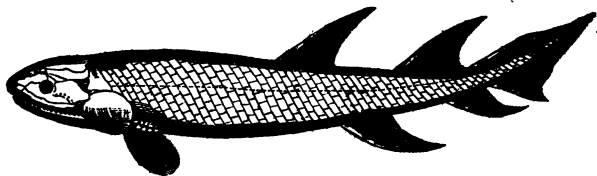
*Holoptychius Nobilissimus*.

figure more closely approximates to that of existing fishes, with a tail and fins as organs of locomotion. In other genera, the plates pass by gradations into bony scales, regularly ar-

ranged, so as to join or overlap each other. This structure is well illustrated by the *osteolepis* (Gr., *osteon*, a bone, and *lepis*, a scale), which presents the form of a perfect fish furnished with pectoral, abdominal, and caudal fins. In the *osteolepis* (see figure) the bony scales are placed alongside each other like the bricks in a building; calculated at once to afford a strong protection to the internal parts, and to yield to the bendings of the body while in motion. In the previous forms of animal life, the organs of motion are but imperfectly developed;



Osteolepis.

but in the *osteolepis* a great advance is exhibited, its fins, tail, and elongated form of body being such as to combine strength with agility. Some families of these early fishes are furnished with spiny fins, or are otherwise armed with detached spines from two to five inches in length, and which are known to geologists by the name of *ichthyodurites* (Gr., *ichthys*, a fish, *doru*, a spear, and *lithos*, a stone). In all of them the tail is unequally lobed, like that of the shark—a character which distinguishes cartilaginous from osseous fishes; the shark, dog-fish, sturgeon, &c. belonging to the former, the cod her-ring, salmon, &c. to the latter division. (Par. 181.)

175. From what we have seen of the fossil flora and fauna of this system, they seem to indicate a condition of life higher in point of development than that which existed during the deposition of the grauwacke and silurian rocks. The cephalaspis, coccosteus, and ptericthys, are successive advances upon the simply organised asaphus; and the holoptychius, osteolepis, and glyptolepis, belong to orders still more fully developed than the ptericthys. But while this advance in the scale of organisation took place, some peculiarity in the waters of the ocean, or other condition, seems to have prevented the increase of previously existing orders; for in none of the beds of the old red sandstone do we find the corals, shell-fish, and crustacea of the silurian system. It is true that in the lower, or flagstone series, remains of crustaceans have been discovered; but in such an imperfect state, that it is impossible to decide what analogy they bear to those of the silurian limestones.

Again, the vegetation which existed during the formation of the grauwacke rocks seems to have vanished almost entirely while the deposition of the old red sandstone was going forward; for, unless at a few detached points, do we find anything like a vegetable organism throughout the whole mass of the formation.

176. *The conditions of the world during the deposition of the old red sandstone* are but imperfectly indicated by the fossil organisms to which we have adverted. Flanking the primary and transition hills, the old red sandstone is eminently a littoral deposit, the lower or gray micaceous series evincing sediment in calm water, the sandstone and conglomerate beds the action of currents and other aqueous agitation, and the yellow beds a recurrence of calm deposition. Many of the strata present the *ripple mark* of the tide as perfect as that now to be traced on the sands of the existing shore; and the conglomerate throughout its entire composition points to causes analogous to those by which the gravel-beaches of the present day are collected. The colouring matter (peroxide of iron) of the formation shows that the waters must have been impregnated with mineral solution, so as to be deleterious to animal life; and it is a curious corroboration of this fact, that the fossil fishes are most abundantly found in the flagstone and yellow sandstone series—the strata least coloured by the metallic impregnation. Whence the metallic oxide was obtained by which the formation is more or less tinged throughout, is a matter of hypothesis among geologists; but that opinion which ascribes it to volcanic origin is the most commonly entertained, and indeed the only one which seems adequate to account for the phenomenon. If, then, the old red sandstone period was one of extraordinary volcanic disturbance, rendering the earth and atmosphere less capable of nourishing an abundant vegetation, and poisoning the waters against the development and propagation of animal life, the student may readily perceive why organic remains should be so scantily disseminated through its material, even while an advance was being made in the kind and character both of vegetable and animal existence.

177. *The igneous rocks associated with the system*, and by which it has been upheaved into its present position, are greenstone, claystone, porphyry, felspar, amygdaloid, and many other varieties of trap. Occasionally, the trap is cut through by dykes of more recent greenstone, felspar, and serpentine; but true granitic rock is seldom or ever in intimate connexion with any portion of the series. By the termination of the old red sandstone deposit, the *granitic igneous era* may be

said to have passed away, and to have been succeeded by that of the *trap*—an era which produced more complicated displacements and contortions of the stratified rocks, though less extensive and gigantic elevations. In Scotland, the *Gramians* belong to the former era, the *Ochils* to the latter; two ranges which, even to the untutored eye, present so many points of dissimilarity both in their external contour and internal composition, as at once to be ascribed to different eras. The volcanic forces which were smouldering throughout the whole formation of the old sandstone, seem, at the conclusion of the deposit, to have spent themselves in one gigantic paroxysm, and to have upheaved the newly-consolidated strata into mountain ridges of extreme irregularity, along whose flanks, as they extended seaward, were deposited *unconformably* the strata of the succeeding formation.

178. *The extent of country occupied by the old red sandstone* is very great, owing, in many instances, to the flat position of the strata, which thus cover a larger amount of surface than they would have done had they been highly inclined like the primary formations. All the members of the series are widely developed in Scotland; the lower portions occur between England and Wales, in Ireland, and in Germany; the middle portions occupy extensive areas in Russia and the flats of Central Europe, in Siberia and Tartary, and flank also the southern *Himmalehs*; and different members of the system occur in various districts of North and South America, as well as in Central Africa.

179. *The geographical features of red sandstone districts* are in general varied and irregular; the hills being less bold and precipitous than those of primary formations, and more lofty and undulating than those of any subsequent period. Where the strata lie flat, and comparatively unbroken, the scenery is rather uninteresting; but the soil is light and fertile, being based on sand, gravel, or reddish clay, composed of the debris of the formation. On the other hand, the mountains of the old red sandstone exhibit great diversity of scenery: rising in easy undulations, sinking and swelling in every direction, yet preserving a common continuity of range, they present in the chain a succession of rounded heights and cones; but in the mass, an irregular surface of hills and valleys, glens and recesses, of great beauty and amenity. The *Ochils* and *Sidlaws*, in Scotland, with their intervening valleys, belong exclusively to this formation, and may be taken as the type of its physical features.

180. *The minerals of commerce* derived from the old red sandstone are comparatively few. From the lower group of

beds are obtained those thin schists of gray micaceous sandstone so generally employed in foot-pavements, in roofing and in flooring; hence the terms *tilestone* and *flagstone*. From the superior red and yellow groups, building-stones of various quality are obtained; but none of these are of great beauty or durability. The claystone, porphyries, and felspars, are exceedingly durable; but are seldom used by the builder, owing to the difficulty of hewing them into form. From the trap, some of the best material for macadamising is obtained in the lowlands of Scotland; while among the debris of the same rocks, the lapidary finds many *geodes* of the finest chalcedonies, agates, jaspers, and carnelians.

CLASSIFICATION OF FOSSIL FISHES.

181. Before proceeding with our description of the succeeding formations, it will be necessary to advert to the system of classification which has been adopted in reference to fossil fishes, inasmuch as it differs from that which Cuvier applied to existing races. This celebrated naturalist collected the whole number of species into two groups, according to the nature of the skeleton and the hard parts—one group embracing the OSSEOUS, or bony, and the other the CARTILAGINOUS fishes. The former group he further separated into two orders—the *Acanthopterygian*, or thorny-finned, and the *Malacopterygian*, or soft-finned. This method, however, does not meet the wants of the geologist, because the skeleton is seldom or ever found in such a state as to answer the purposes of classification. Fossil scales, teeth, spines, and fragments of fishes, are found in abundance, but these afford too imperfect data for arrangement; and when an entire specimen occurs, it is merely the general shape and character of its scaly covering upon which the ichthyologist can decide with certainty. Proceeding upon this principle, M. Agassiz takes the dermal covering as the foundation of his system—the skin being that organ which indicates not only important structural and functional differences, but also shows the relation of every animal to the element in which it moves.

182. *Instead of the divisions Osseous and Cartilaginous, he distinguishes four great orders of fishes according to the nature of their scales, and finds that other important distinctions of structure, &c. harmonise with these differences of scales. This discovery is invaluable; for, of all parts of fishes, the scales are those most abundantly found in a fossil state; and if by a single scale the geologist can detect the order to which any fish belonged, he has also a clue to its habits and mode of life, and to the conditions under which it flourished. The follow-*

ing is a sketch of the principal divisions and subdivisions proposed by M. Agassiz :—

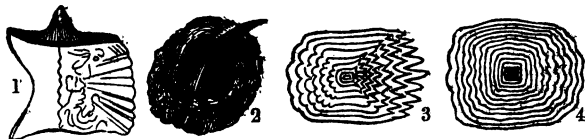
I.—SCALES ENAMELED.

1. GANOIDIANS (Gr., *ganos*, splendour, from the bright surface of their enamel).—The fishes of this order are covered with angular scales, composed internally of bone, and coated with enamel. The scales are *regularly* arranged, and entirely cover the skin. The sauroid fish, or those which, from the structure of their teeth and other peculiarities, approximate to reptiles, are amongst the most interesting of this order. Nearly all the species referred to it are extinct; the *sturgeons*, and *bony-pikes* of the North American lakes, are living examples.
2. PLACOIDIANS (Gr., *plax*, a broad plate).—Fishes of this order have their skin covered *irregularly* with *plates of enamel*, often of considerable dimensions, but sometimes reduced to small points, like the shagreen on the skin of the shark, and the prickly tubercles of the ray. It comprehends all the cartilaginous fishes (*sharks and rays*), with the exception of the sturgeon.

II.—SCALES NOT ENAMELED.

3. CTENOIDIANS (Gr., *kteis*, genitive *ktenos*, a comb).—Ctenoid fishes have their scales of a horny or bony substance without enamel, jagged like the teeth of a comb on the outer edge. The *perch*, and many other existing genera, are of this order, which contains but few fossil forms.
4. CYCLOIDIANS (Gr., *kyklos*, a circle).—The fishes of this order have smooth, horny, or bony unenameled scales, entire at the margin, with concentric or other lines on the upper surface. The *herring*, *salmon*, &c. belong to this order, which, along with the former, includes almost the whole number of existing species.

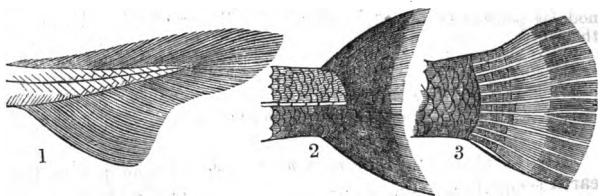
Such are the divisions proposed by M. Agassiz, and now universally adopted by geologists, although it is not unlikely that a more perfect system may soon be propounded, which will embrace in one category both fossil and existing species. The subjoined engraving more summarily represents the four orders of scales above alluded to:—



1. Ganoid; 2. Placoid; 3. Ctenoid; and, 4. Cycloid, Scales.

183. *Each of these orders contains both bony and cartila-*

ginous fishes. The representatives of each prevailed in different proportions during different epochs; the two first (enameled scales) existed before the commencement of the chalk system; the third and fourth orders, which contain nearly five-sixths of living species, appear for the first time in the chalk strata, when all the preceding fossil genera of the two first orders had become extinct. Another remarkable circumstance observed by M. Agassiz is, that all, or nearly all, the fossil fishes found in strata beneath the magnesian limestone are *heterocercal*, that is, have their tails *unequally bilobate* (see fig.), like the shark, sturgeon, lepidosteus, &c.; while this form of tail is rarely found in the oolite and superior strata. Among existing fishes,



1. Heterocercal, or Unequally bilobate; 2. Equally bilobate; and, 3. Single and rounded, forms of tail.

the tail, or caudal fin, is generally *equally bilobate*, as in the trout; or *single* and rounded, as in the wrasse; but seldom heterocercal. This latter form is produced by a remarkable prolongation of the vertebræ, which bears a striking analogy to the prolongation of the same parts in reptiles; thus connecting the cartilaginous fishes with the reptilia, not only by internal structure, but also by the evidences of external form.

EXPLANATORY NOTE.

OLD RED SANDSTONE.—To this system English geologists sometimes apply the term “Devonian,” because it happens to be very extensively developed in Devonshire. Distinctions of this kind are always objectionable, and particularly in the present instance, where the general term, Old Red Sandstone, is so eminently descriptive.

PEROXIDE OF IRON.—When the oxygen of common air unites with the atoms of iron, an *oxide*, or rust, of iron is the result; and when this rust has absorbed as much oxygen as it is capable of, it is then termed a *peroxide*, or thorough oxide, of iron.

ICHTHYOLITE (Gr., *ichthys*, a fish, and *lithos*, a stone).—A fish, or any part of a fish, found in a fossil state, is termed an ichthyolite.

PUDDINGSTONE—any conglomerate of rounded pebbles cemented together by a silicious or sandy paste. When select specimens are

cut and polished, they resemble a section of a plum-pudding ; hence the term *puddingstone*.

PORPHYRY (Gr., *porphyrā*, purple).—This term was originally applied to a reddish unstratified rock found in Egypt, and used by the ancients for statuary purposes. It is now employed by geologists to denote a reddish igneous rock containing imbedded crystals of felspar ; and all rocks (whatever their colour) which contain imbedded crystals distinct from their mass, are said to be *porphyritic*. We have thus felspar porphyry, porphyritic granite, and porphyritic greenstone.

AMYGDALOID (Gr., *amygdalon*, an almond, and *eidos*, a form)—almond-shaped. The term is applied to certain trap rocks in which other minerals are occasionally imbedded like almonds in a cake. Some varieties of amygdaloid are locally termed *toad-stones*, from the resemblance which their colour and makings bear to that of a toad's skin.

GEODES (Gr., *geodes*, earthy)—a term applied to rounded pebbles having an internal cavity lined with crystals ; also to rounded or nodular pebbles themselves ; and to nodules of ironstone hollow in the centre.

CARBONIFEROUS SYSTEM.

184. At the close of the Old Red Sandstone period the earth seems to have undergone an almost total change in its geological conditions. The red sandstones and gravelly conglomerates which had been formed along the shores and bottom of the sea, were upheaved into dry land ; thus adding to the extent of land previously existing, and gradually circumscribing the limits of the ocean in which subsequent deposits were to take place. As disintegrated granite furnished the felspar, quartz, and mica of the gneiss and mica schist, and as from these, again, were obtained the materials of the clay-slate, grauwacke, and silurian rocks, so from all these, together with the newly upheaved red sandstone, were derived the material of the succeeding formation. These successive attritions would reduce quartz to sand of various fineness, felspar to loose impalpable clay, mica from large plates to minute scales, and crystalline limestone to a dully powdery consistence. The rocks formed of these ingredients would necessarily present a less compact texture ; and thus it is in the Carboniferous System that the sandstones are more arenaceous, the shales soft and earthy, and the limestones non-crystalline and often impure. Besides the sandstone, clay, and limestone, two new rock substances make their appearance among the strata of this system, namely, *coal* and *ironstone*—the former being the result of compressed and altered vegetation, and the latter a chemical aggregation of the metallic particles around some earthy basis. The iron of the old red sandstone was

disseminated through the mass as mere colouring matter; in the carboniferous formation it is principally collected in layers, or in nodules. The vegetation of previous periods was so scanty, as to leave only a few dubious impressions among the strata. During the era about to be considered, it was so abundant, as to form numerous beds of coal, ranging in thickness from a few inches to twenty or even thirty feet.

185. The term "*Carboniferous*" has been applied to this system from the fact, that vegetable deposits—of which the main solid element is *carbon*—constitute its most distinguishing feature. It is regarded by many as marking the commencement of the SECONDARY PERIOD; and holds a position in the earth's crust intermediate between the old and new red sandstones. Having been deposited after the upheaval of the old red sandstone, it rests in many places unconformably upon that system, and occupies smaller and more detached areas, which often assume a basin or trough form, as shown in page 116. It is composed of two very distinct groups, the *mountain limestone* and the *coal measures*, which in some respects require separate descriptions.

MOUNTAIN, OR CARBONIFEROUS LIMESTONE.

186. The distinguishing feature in the mineral composition of this group is sufficiently indicated by the name *Mountain Limestone*. It must not be supposed, however, that it is entirely composed of calcareous beds; but merely that the limestones are the most characteristic members; for many of the inferior strata are pure quartzose sandstones, containing scarcely a trace of lime, and alternating with thin seams of coal and bituminous shales. As developed in the British islands, the group may be said to consist of thick-bedded gray or bluish sub-crystalline limestones, divided by partitions of grits and shales, and of whitish quartzose sandstones of various fineness, separated by subordinate layers of shale, thin seams of coal, and bands of ironstone. It is generally found flanking or crowning the trap-hills which intervene between the old red sandstone and coal measures, presenting bold escarpments; hence the term *mountain limestone*. The epithet *carboniferous* is also applied to it, because it invariably underlies the true coal measures wherever these occur, and is generally associated with thin seams of coal and bituminous shales. Like all stratified rocks, this is broken up by fissures and dislocations caused by subterranean movements; but, independently of these, it is numerously intersected by what are termed *joints* and *divisional planes*—the former being rents

(or *backs*, as they are called by quarrymen) perpendicular to, and the latter *partings* parallel with, the plane of stratification.

187. *The order of succession among the strata of this group* is by no means determinate. In some districts, only a few beds of calcareous shales and grits occur between the limestone and old red sandstone; in others, a vast succession of white quartzose sandstones alternating with bituminous shales, thin seams of coal, and bands of ironstone; while in Fife and Mid-Lothian, these sandstones are associated with strata of shell and fresh-water (?) limestone. Whatever may be the character or thickness of the rocks beneath, the true mountain limestone of itself constitutes a well-marked suite of strata, easily distinguishable from any other. Sometimes it consists of two, four, or six beds, divided by partings of argillaceous matter; at other times the beds are separated by layers of calcareous sandstone and shale; while not unfrequently it occurs in one mass of vast thickness, flanking some trap-hill precisely after the manner in which a coral reef skirts the island around which it is forming. In general, there occur above the limestone calcareous shales, sandstones, and thin seams of coal, which pass into the true coal measures; but in the north of England, there intervenes a series of very pebbly or quartzose sandstones, known by the name of *Millstone Grit*. Notwithstanding these variations, the calcareous members gradually disappear, and the carboniferous become more frequent as we ascend, so that there is no great difficulty in fixing the line of demarcation between the two groups.

188. *The organic remains of the mountain limestone* are eminently marine. It is true that the occurrence of thin seams of coal attest the presence of terrestrial plants which must have been drifted into the sea of deposit; and there is some doubt among geologists as to the origin of certain limestones among the lower strata; but laying these aside, the whole character of the group is as decidedly oceanic as the living coral reefs of the Pacific. The most remarkable advance upon the marine life of former periods, as evidenced by the fossils of the mountain limestone, is that which appears among the Radiata. In the silurian rocks, the corals were chiefly of a sessile kind; in this group many of them are free and independent animals, bearing little or no analogy either to previous or existing forms. The most prevalent of these was the *Orinoid* or *Encrinite* family, of whose exuviae many beds of limestone are almost wholly composed. Of the encrinite (Gr., *krinê*, a lily), or lily-shaped corals, are found many genera and sub-genera—the distinctions being made

from the external figure of the stalk and head. That exhib-



Fig. A.

ited in fig. A may be taken as the type of the class; it is the *encrinites moniliformis*, so called from the necklace-shape of its stalk. Besides the encrinites moniliformis, which is by far the most prevalent of the crinoideans, there were the *pentacrinus*, five-sided instead of round, the *actinocrinus*, or spiny encrinite, the *apocrinite*, so called from the pear-like form of its head, and many others deriving their names from similar distinguishing features. By examining fig. A, the student will perceive that the encrinite consisted of a stalk composed of numerous joints, rendered flexible by means of cartilage, and perforated for the passage of an internal canal; that it was fixed at its base, and supported at its free extremity, a cup-like body (*s*) containing the mouth and stomach; that this cup-like body was composed of many pieces, which branched out into numerous tentacula (*t*) for the purpose of seizing its prey. The whole animal is supposed to have been invested with a gelatinous covering, by which its structure was held together. In the skeleton of some specimens, not less than 26,000 bones, or pieces of calcareous matter, have been counted, all beautifully marked, and ingeniously adapted to each other; and in a framework so liable to be broken, we find traces of a power to reproduce mutilated parts, such as we find in the crabs and star-fishes of the present day. Little more is known of the structure of these crinoidea, or of the habits and pecu-

liarities of the different genera. The seas at this period seem to have swarmed with them; their remains are found in every stratum of a calcareous character, and masses of limestone from 40 to 120 feet in thickness are almost wholly composed of them, just as existing coral-reefs are formed of various corals. In consequence of the complex constitution of the skeleton, and the perishable nature of the enveloping membrane, entire specimens are seldom or ever found; the separate pieces having been drifted and scattered about after the surrounding cartilage was decomposed. Fig. B represents a fragment of moun-

tain or encrinital limestone, which, when sufficiently hard, furnishes a curious and highly ornamental marble.

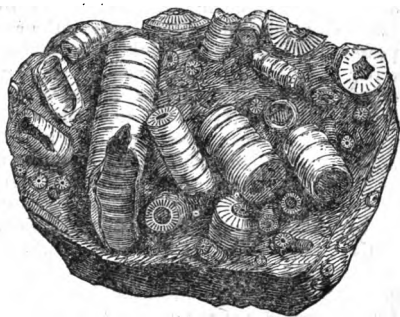
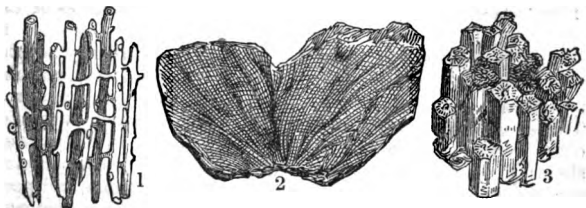


Fig. B.—Fragment of Encrinital Limestone.

189. Besides crinoidea, the mountain limestone contains many other species of radiaria—branched, fungous-shaped, fan-shaped, star-shaped, and tubular. These differ in many instances from the corals of the silurian, as they differ from those of the present day; and are confusedly mingled with corallines, shells, teeth, spines, and scales of fishes. The following engraving represents some of the more prevalent forms among the corals and corallines of this era:—



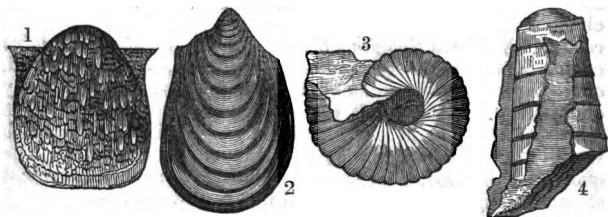
1. Syringipora.

2. Retepora.

3. Cyathophyllum basaltiforme.

190. The shell-fish of this group are also exceedingly numerous, and of curious and gigantic forms. They belong to all orders—equal and unequal bivalves, single and many-chambered univalves; many of them are not to be found in any other strata than those of the carboniferous era. Several families seem (like the oyster and cockle of the present day) to have been gregarious, covering large spaces

of the ocean's bed; for shells are found composing beds of limestone from one to six feet in thickness; others to have been solitary, changing their places as necessity required; while the chambered shells, like the argonaut and nautilus, possessed the power of sinking or floating at pleasure. (See par. 222.) Like existing shell-fish, they appear to have inhabited the seas at moderate depths from the shores, and to have preyed partly on each other, and partly on marine vegetables. Their numbers and size indicate a genial condition of the ocean both as regards temperature and calcareous matter—the former fostering their growth with rapidity, and the latter yielding material for the structure of their shelly coverings. Some of the more typical shells belonging to this formation are the *Producta*, *Terebratula*, *Spirifera*, and *Inoceramus* among the bivalves; and the *Euomphalus*, *Ammonite*, *Bellerophon*, *Orthoceratite*, and *Goniatite* among the univalves, which are chiefly many-chambered.



1. *Producta scabriculus*; 2. *Inoceramus vetustus*; 3. *Bellerophon tangentialis*; 4. *Orthoceras cinctum*.

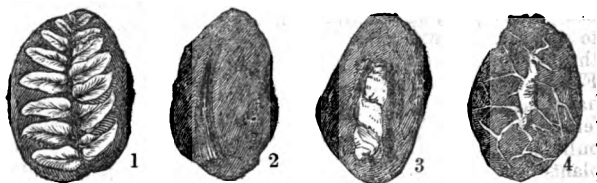
191. *Crustacea and fishes* have been found in all the members of the carboniferous system, from the lowest beds of the mountain limestone to the highest of the coal measures. The *crustacea* are chiefly trilobites, though broken plates of other genera are not uncommon; and some of the calcareous shales yield species bearing a faint analogy to the *chiton* of modern seas. The trilobites of the mountain limestone, however, are less numerous and varied than those of the silurian era, of whose Fauna it will be remembered they formed the most distinguishing feature. *Ichthyolites* are exceedingly numerous, either as entire fishes, detached scales, spines, teeth, or coprolites. The fishes belong for the most part to the Ganoid order, though Placoidians are not unfrequent. Many of these are of gigantic size, such as the megalichthys (large fish), holoptychius, &c. and bear so much analogy to reptiles in the bones of their head and external coverings, as to induce M. Agassiz to term them "sauroid fishes." Their

palatal bones, spines, and teeth are found in abundance, some of the latter being more than four inches in length—thereby denoting the gigantic size of these predatory animals. Their coprolites (Gr., *kopros*, dung, and *lithos*, a stone), or fossil excrements, are scattered throughout the shales and calcareous strata, and attest, by the fish-scales, bones, &c. which they contain, the nature of the food on which they subsisted.

COAL MEASURES.

192. The term "*Coal Measures*" is applied to that series of rocks which immediately overlies the mountain limestone, and from which the well-known mineral, *coal*, is obtained. The group is composed of alternations of coals, sandstones, shales, bands of ironstone, fire-clay, and layers of impure limestone. The coals present every degree of fineness and purity, and are generally distinguished as follows:—*Anthracite*, a hard, shining variety, destitute of bitumen, often called mineral charcoal; *caking*, a highly bituminous sort, like that of Newcastle, which cakes or runs together during combustion; *cubic*, less bituminous, breaking up into cubical masses; *cannel*, a compact lustrous variety, which breaks with a conchoidal fracture; *jet*, still more compact and lustrous; and *lignite*, or brown coal, in which the woody structure of the vegetables is still perceptible. The sandstones are in general quartzose, of a dull-white or brown colour, and thick-bedded; sometimes they are flaggy, or schistose, and in this instance are either of a calcareous or argillaceous character. The shales are all dark-coloured, and bituminous; the fire-clays grayish-white, and more or less sandy; the ironstone occurs either in bands or nodules; and the limestones are all earthy and impure. The ironstone of earlier formations occurs either in veins, or is disseminated as colouring matter through the mass; in this system it appears as an argillaceous carbonate, either in thin layers from one to twelve inches thick, in irregular nodules, or in bands of regular nodules, called *septaria*, from the nodule being often internally divided into numerous *septa*, or partitions, as shown in 4 of the following engraving. These nodules seem to have been formed by some process of attraction round a central nucleus, as in nine cases out of ten they contain nuclei of leaves, teeth, scales, or spines of fishes, coprolites, or some other organic matter. Beneath is represented as central nuclei—1, a fragment of a plant; 2, a fish-tooth; 3, fossil excrement, or coprolite; and, 4, true *septaria*, with their curious partitions of white carbonate of lime, giving the section the appearance of a beetle; from

which circumstance such nodules are known in some places as *beetle-stones*.

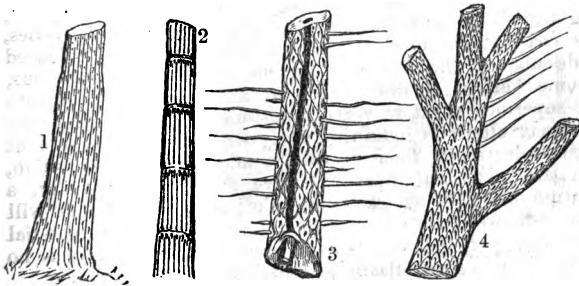


Ironstone nodules, showing varieties of central nuclei.

193. *There is no regular succession among the beds of this group*; though it may be remarked, that the thickest and best seams of coal abound about the middle of the series. Immediately above the mountain limestone the coal beds are thin, the shales thick-bedded, and more or less calcareous; and the sandstones often calcareous and argillaceous. As we ascend, the argillaceous and calcareous members become less prevalent, the coals thicker and more frequent, and the shales more bituminous. Further up in the series, the coals gradually disappear, fire-clays and light-coloured shales abound, the sandstones become more purely arenaceous, assume various shades of colour, and insensibly pass into the superincumbent new red sandstone. In general, all the members alternate indiscriminately with each other, present various degrees of fineness, colour, and mineral composition, and are persistent over extensive areas. Occasionally, a stratum will *thin out* and disappear; at other times it will part, as it were, into two, with a layer of different material between; yet, notwithstanding such anomalies, there is no series of strata so regularly deposited as the coal formation.

194. *In the organic remains of the coal measures*, the abundance of terrestrial vegetation is by far the most distinguishing feature: though, as might be expected from the nature of the deposit, marine shells, fishes, and other aquatic exuviae are not unfrequent. It has been already stated that coal is of vegetable origin; in other words, that its mass is composed of plants altered by compression and that process of bituminization described in par. 115. On account of this change, it is often impossible, at first sight, to detect any trace of vegetable structure; but on closer inspection, the woody fibre may be seen in many specimens; while it is possible in almost all to make visible the cells and fibre by exposing thin slices to the transmission of a powerful light. In

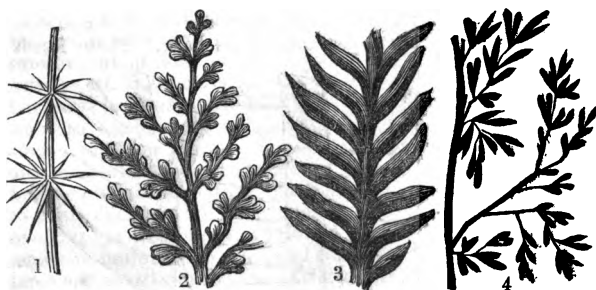
this way Mr Witham observed the various vegetable tissues in coal, thereby adding another testimony to the numerous evidences of its organic origin. In most of the bituminous beds, however, the external form is obliterated, and it is to detached fossils in the sandstones and lighter shales that the geologist is indebted for his knowledge respecting the Flora of the carboniferous era. About four hundred species have been already determined, chiefly gigantic equisetums, ferns, club-mosses, cactuses, pines, and plants allied to the bulrush, cane, and bamboo. Most of these resemble existing plants merely in their generic distinctions, having belonged to species which flourished during the coal-forming period, and became extinct with the peculiar conditions of the globe which gave them birth. Some of the most characteristic of the vegetable fossils belonging to this formation are represented beneath; namely—1. *Sigillaria*, so called from the graven appearance of its stem; 2. *Calamites*, from the reed-like jointings of its stalk; 3. *Stigmaria*, from its stigmata, or punctures; 4. *Lepidodendron* (Gr., *lepis*, a scale, and *dendron*, a tree), from the scaly appearance of its bark. These fossils



1. *Sigillaria pachyderma*; 2. *Calamites cannaeformis*; 3. *Stigmaria ficoides*; 4. *Lepidodendron Sternbergii*.

occur in all the members, from the lowest white sandstone beneath the mountain limestone, up to the commencement of the new red sandstone, at which stage they disappear, and do not seem to have flourished during the deposition of any subsequent formation. The best preserved specimens are found in the shales and sandstones; the interior structure of the plant being converted into soft quartzose sandstone, and the bark, or cuticle, into a glistening bituminous coal. In the coal, the vegetable structure is always more or less obliterated, though sometimes a solitary trunk occurs of the same quart-

zose material as those imbedded in the shales and sandstones. Of these fossil trees, many have been found of gigantic dimensions; as, for example, a lepidodendron in the Jarrow coal-field $13\frac{1}{2}$ feet wide at the base, and 30 feet high, exclusive of the branches at the top, which were also entire; and a conifera of the genus *auracaria* in Craigleith quarry, 3 feet in diameter, and 20 feet long. Besides the sigillaria, &c. above described, there are numerous species of tree-ferns, club-mosses, equisetums, and other cryptogamic plants preserved in the shales; their dark carbonaceous leaves and branches being often beautifully displayed upon the light-coloured ground of the material in which they are imbedded. Of these the following engraving exhibits some of the most characteristic; namely, *Asterophyllites* (Gr., *aster*, a star, and *phyllon*, a leaf); *Sphenopteris* (*sphen*, a wedge, and *pteron*, a wing); *Pecopteris* (*pekos*, a comb, and *pteron*, a wing); all so named from the shape of their respective leaves.



1. Stem and leaves of *Asterophyllites*; 2. *Sphenopteris linearis*; 3. *Pecopteris Mantelli*; 4. *Sphenopteris affinis*.

195. Of the conditions of the world during the deposition of the carboniferous system, we have more obvious evidence than of those under which any of the earlier systems were formed. The extent of the seas in which the deposit took place is very clearly indicated by the course of the mountain limestone, which must have been formed at no great depths from the shore, as its corallines, corals, shells, and other exuviae, prove it to be of littoral origin. All the members of the system, with the exception perhaps of the limestones, are eminently sedimentary; and the numerous alternations of these strata evince frequent changes in the depositing agents. At one time the rivers seem to have carried down sand to form

sandstones, at another clay and mud to form shale, and at a third period vegetable drift to form coal; for strata of these materials often directly overlies each other. It must be borne in mind, however, that sand, clay, and plants, might be carried down at the same time, and that they would arrange themselves according to their gravity—the sand depositing itself along the shores, the mud farther seaward, and the vegetables in any still bay where currents of wind or water might drift them. Such an arrangement would take place under the ordinary operations of water; but during violent inundations, there would be a confused intermingling of sand, mud, and plants, and this we often discover; so that, taking all things into account, we learn that the same agencies of rivers, waves, and tides, existed during the deposition of the carboniferous rocks as exist at the present day, only on a more gigantic and uniform scale. Looking at the abundance of marine life which must have thronged the waters during the formation of the mountain limestone, and at the vast amount of vegetation which the earth must have sustained while the deposition of the coal measures took place, we are led to infer that the earth then enjoyed a much higher and more uniform temperature than it has ever since experienced. At present, we find a faint analogy in the Fauna of the tropical seas, and in the Flora of the tropical jungles, to those of the carboniferous era; but so faint, that we can scarcely institute a comparison between the results produced. The coral-reefs of the Pacific are insignificant compared with the thickness and extent of the mountain limestone; and the vegetable drift of the Mississippi and Ganges combined, would scarcely produce carbonaceous matter sufficient to colour one stratum of shale. Notwithstanding this, there is a resemblance between the coral productions of the Pacific and those of the mountain limestone; and between the palms, tree-ferns, canes, and cactaceæ of the tropics, and the fossil plants of the coal measures. The heat of the tropics is directly derived from the sun, and the torrid zone occupies but a narrow belt of the earth's surface; whereas the coal measures are to be found almost in every region of the globe. The sun could not, therefore, have yielded that temperature which nourished the plants and animals of this period; for though the sun's heat had been greater than at present, it could not have been universally diffused. The conclusion, therefore, to which most geologists have come, is, that the earth, originally an incandescent mass, was gradually cooled down—hot enough to render gneiss and mica schist crystalline; cool enough during the grauwacke and silurian eras to permit of marine corals, shell-

fish, and crustacea; cooler still during the life of the plated fishes of the old red sandstone; and only sufficiently genial throughout the deposition of the carboniferous period to foster a growth of terrestrial vegetation all over its surface, to which the existing jungles of the tropics are mere barrenness in comparison. This high and uniform temperature, combined (as suggested by Brogniart) with a greater proportion of carbonic acid gas in the atmosphere, would not only sustain a gigantic and prolific Flora, but would also create denser vapours, showers, and rains; and these, again, gigantic rivers, periodical inundations, and deltas. Thus all the conditions for extensive estuary deposits would arise from this high temperature; and every circumstance connected with the coal measures points to such conditions.

196. *With regard to the formation of coal*, geologists are not yet fully agreed. On examining sandstone or shale, it is easy to perceive from their structure, texture, and composition, that they must at one time have been respectively loose sand and mud, borne down and deposited by water; but the case is somewhat different with beds of coal. This mineral, being chiefly composed of carbon, hydrogen, and oxygen—the same elements which enter into the composition of plants—and revealing in its mass evidence of vegetable structure, no doubt is entertained of its organic origin. But whether the plants of which it is composed were drifted down by rivers, and deposited along with layers of mud and sand in estuaries, or whether dense forests and peat-mosses were submerged, and then overlaid by deposits of sand and mud, are the questions at issue. According to the latter hypothesis, the vegetable matter must have grown in dense jungles for many years; then the land must have sunk, and become the basin of a lake or estuary, in which situation rivers would wash into it mud and sand, and these would cover the vegetable mass, and form beds of shale and sandstone. This being done, it is supposed that the area of deposit was again elevated, so as to become the scene of luxuriant vegetation; again submerged, and overlaid by new deposits of sandstone and shale; once more elevated, and covered with plants, and then submerged: and this alternating process of submergence and elevation is contended to have taken place as often as there are beds of coal in any particular coal-field. The other theory is, that while partial elevations and submersions might take place as at the present day, the great mass of the coal measures was deposited in lakes and estuaries; that the vegetable matter of which coal is formed was drifted into these estuaries by rivers and inundations; and that various rivers might discharge

themselves into one estuary, some chiefly carrying down sand, while others transported plants, mud, and heterogeneous debris. This theory also supposes that the transporting rivers were subject to periodical inundations, and that, during the intervals of overflow, the deltas were choked with a rank vegetation, which, in conjunction with the vegetable drift from inland, went to the formation of beds of coal.

197. *Both theories are at present beset with many difficulties ;* but the latter is the more generally received, as accounting for most of the phenomena connected with our coal-fields. According to the former theory, a submergence and elevation must have taken place for every seam of coal ; and as in some districts from thirty to forty seams occur, varying in thickness from a few inches to many feet, it is impossible to conceive how the earth, in this unstable condition, could have nourished such a prolific Flora as the coal measures clearly demonstrate. It is also justly objected against this theory, that some thick beds of coal are subdivided by thin layers of sandstone, or ferruginous shale, a fact which would imply that many elevations and submergences took place even during the formation of a single coal bed ; whereas by the latter theory, those layers of sandstone, &c. present no difficulty, as the river, while it bore down vegetable drift, would carry at the same time sand and other debris. Further, shells and fishes are sometimes found imbedded in coal ; and it is difficult to conceive how these could have got there, unless in the ordinary way of deposit and sediment. Forests of coniferæ, palms, and tree-ferns, could not have been submerged and covered up with sand and mud, without the trunks being abundantly found in an upright position ; now, this upright position of fossil trees is rarely or ever met with. Again, had coal resulted from submerged peat mosses, instead of from growing forests, there is no means by which we can account for the occurrence of shells, fishes, and thin layers of sandstone in its mass. By the latter theory, all these can be readily accounted for. Over vast deltas, such as those in which it supposes the coal measures to have been deposited, there would not only occur growing stems of palms, ferns, reeds, and the like, to be silted up perpendicularly, but there would also occur morasses choked up with a rank growth of grasses, while in the creeks and lagoons, shell-fish, fishes, and other aquatic life would abound. In the deltas of existing rivers, the latter theory meets with a perfect analogy ; and when the student is told of the rafts of the Mississippi, the mangrove jungles of the Niger, and the sand and mud-banks of the Ganges (par. 279, 280, &c.), he can have little

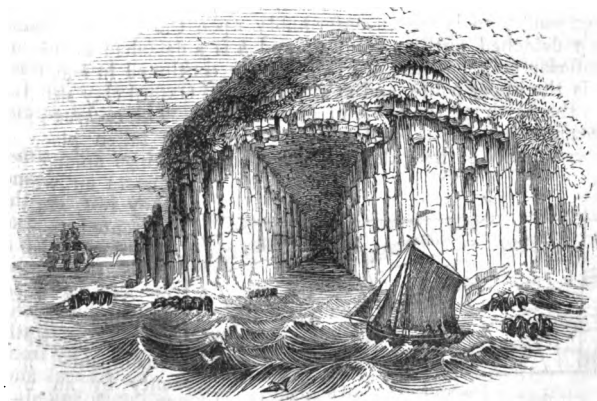
difficulty in forming a conception of the estuaries in which the sandstones, shales, shell limestones, and coal of the carboniferous era were deposited.

198. *The igneous rocks associated with the carboniferous system* are all of the trap family—greenstones, clinkstones, basalts, trap-tuffs, &c. They are principally composed of felspar and hornblende, with admixtures of clay, augite, and occasionally hypersthene. The *greenstones* (vulgarly, whinstones) occur in large indeterminate or tabular masses, and are often hypersthene; the *clinkstones* differ little from the greenstones in mineral composition, but are more compact, split up into thin schistose-like fragments, and yield a metallic sound when struck by the hammer; the *basalts* are easily known by their columnar structure, their dark and compact aspect, and from their containing little spherical crystals of a greenish mineral called *olivine*; and the *trap-tuffs* are of all varieties, from a soft scoriaceous-looking mass to a confused conglomerate of fragments of basalt, greenstone, sedimentary rocks, &c. The trap rocks of the carboniferous era are easily distinguishable from those of any other, partly by their darker colour, and from the fact of their yielding more or less bitumen by distillation; and partly from the prevalence of basalts, and of trap-tuffs containing fragments of limestone, sandstone, and shale. Among the traps of the old red sandstone, felspar, porphyries, and amygdaloids prevail, but are rarely to be met with among those of the coal measures; while, on the other hand, the traps associated with the tertiary strata assume a lighter colour, and a decidedly scoriaceous and lava-like aspect.

199. *The positions of the carboniferous trap rocks are either* disrupting, overlying, or interstratified. They disrupt and elevate, as in the mountain limestone hills, and in the rounded heights and isolated irregular cones of the coal measures. Basalt, or greenstone, sometimes overlie, as if poured in a state of liquid lava over the subjacent strata; and trap-tuffs also overlie, from their evidently having been thrown abroad in the form of volcanic dust and ashes. The trap rocks of this era more frequently assume the interstratified form than those of any other formation; apparently from the fact, that volcanic discharges took place in the seas and estuaries in which the coal measures were being deposited—these discharges, whether in the form of lava or ashes, being overlaid by subsequent deposits of sedimentary matter.

200. *The structure and texture of these igneous rocks differ* as widely from the granitic series beneath as from the volcanic above. They are generally close-grained, and less

distinctly crystalline than the former, and more compact and less vesicular than the latter. The structure of the tuffs and porphyries is massive and indeterminate; of the greenstones sometimes massive, but generally tabular or cuboidal; and of the basalts always columnar. This difference in the structure and texture of these rocks seems to have arisen not so much from any difference in their mineral composition, as from the circumstances attending their cooling. This has been satisfactorily proved by the experiments of Sir James Hall and Mr Gregory Watt, who, by fusing various kinds of trap, produced, by different modes of cooling, not only columnar basalt, but spherical greenstone and vesicular tufa. The same substance which, when suddenly cooled, forms a black glass or *obsidian*, will, by a slower process of refrigeration, form basalt, or, by a still slower, pass into earthy tufa. By gradually cooling the fused mass, columnar basalt may be formed; but if, at a certain stage of the process, it be rapidly cooled, spherical masses will be produced, which, when exposed to the weather, *exfoliate*, or decompose coating after coating. By these experiments, it was also proved that the primary form or crystal into which volcanic rock arranges itself when cooled, is spherical; and by these spheres pressing

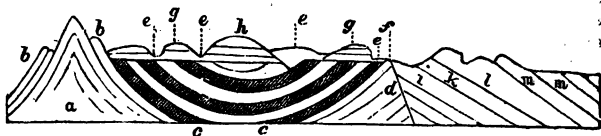


Staffa—Fingal's Cave.

upon each other, are produced tabular, cuboidal, and columnar forms. This fact can be readily illustrated by putting a number of spherical pellets (of putty or any other yielding

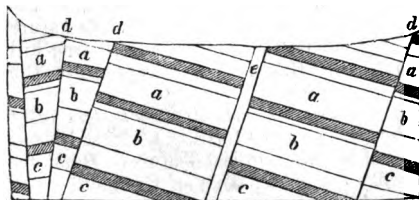
material) into a vessel, and then gently pressing upon them, when they will be seen to arrange themselves in five and six-sided columns, precisely similar to the five and six-sided columns of Staffa, or the Giant's Causeway.

201. *The effect of igneous forces upon the coal measures* has been to throw them into troughs and basins, to elevate and depress them in a very extraordinary manner. The following engraving represents a section of the South Gloucestershire coal-field (omitting faults), and may be taken as the type of the trough or basin.



Trough or Basin Form of Coal-fields.

Mendip hills, overlaid by the old red sandstone *d*; *b b* are strata of carboniferous limestone resting at a high inclination upon the slopes of the hills, and reappearing at *f*; *c c* and the other darkened layers are beds of coal; *e e e* denote the new red sandstone lying unconformably upon the coal measures; *g g* detached outliers of lias; and *h* is a detached outlier of inferior oolite, which are respectively continued in *i* and *k*; *l* is the upper oolite, and *m m* are beds of Oxford clay situated to the north of the town of Malmesbury. The *upthrows* and *downthrows* of the coal strata, which have taken place in consequence of irregular upheavings and sinkings among the



Dislocations of Coal Strata.

masses on which they rest, are represented in the subjoined figure. Here the *faults* or *slips* *d d d*, and the dyke *e*, are respectively accompanied not only by an upthrow or downthrow, but also by a different inclination of the strata. This mode of fracture is of frequent occurrence in every known coal-field, showing in a striking manner the nature of the agitations which have taken place below. In the vale of the Esk, in Mid-Lothian, which does not measure more than ten

miles each way, the coal-field shows 120 ascertained dislocations, one of which, at Sheriffhall, throws down the strata 500 feet. In the Newcastle coal-field, there is a famous slip called the *ninety-fathom hitch*, the deviation from the line of stratification being no less than 450 feet. The coal-fields of Fife and Clackmannan abound in such dislocations, several of them throwing the strata from 400 to 1200 feet up or down, as the case may be, from the general position.

202. *The extent of country occupied by the carboniferous system* is not great, the deposit being found only in limited and detached areas. It occurs largely in the British islands, and to this circumstance is mainly owing our greatness as a nation—the formation being rich in coal, iron, and lime—three of the most essential minerals to civilised existence. It presents itself in the Lowlands of Scotland, in the northern and middle districts of England, in Wales, and in Ireland; it occurs also in some districts of Spain, in central France, Germany, and in Middle Europe; in Hindostan, in Australia, and New Zealand; in the island of Batavia, and on the eastern coast of China; in Melville island; in Nova Scotia, and in the States of North America.

203. *The physical aspect of carboniferous districts* is rather tame and unprepossessing. The hills connected with the mountain limestones sometimes present considerable variety of scenery, owing to the bold escarpments of that rock, its extensive fissures and caverns, and the irregular undulations of the trap. These features are also aided by the general verdure and fertility of limestone districts, which present a freshness and luxuriance peculiar to themselves. The coal districts are almost always tame and unattractive, relieved by few elevations or depressions of picturesque beauty, and being, in general, bleak and unfertile from the cold and retentive nature of the soil. Occasionally, a basaltic crag or isolated trap-hill relieves the monotony; but this is the exception to the general rule.

204. *The economical value of the carboniferous system* fully compensates for any deficiency in the fertility of its soil, or in the picturesque beauty of its geographical features. *Building-stone* of the finest quality (of which that of Craigleith, near Edinburgh, and of Calelo in Fife, are good examples) are obtained from the sandstones beneath the mountain limestone; while the millstone grit and flaggy beds of the coal measures yield other valuable freestones. Of all the limestones in the crust of the earth, the *Mountain* is that which is most valuable and abundant; and from it are principally derived those stores of *lime* so indispensable to the purposes of the builder,

agriculturist, iron-founder, &c. Where the encrinal beds are sufficiently hard and crystalline, they furnish a very prettily-marked *marble*; the joints, stalks, plates, and star-like tubes of the corals shining out from the darker matrix in which they are imbedded. Many ornamental *spars* (Derbyshire spar) are found in the veins of the mountain limestone, which are also the principal sources of *lead ore* in the British islands; Derbyshire, Alston Moor in Cumberland, and Lead Hills in Lanarkshire, being well-known lead-mining districts. *Silver* and *gold* are both more or less associated with the ores of lead, especially the former; but they are seldom sought after, unless in connexion with lead. *Fire-clay* is dug up from the coal measures for the making of fire-bricks, furnace linings, &c.; *ochre* (hydrated oxide of iron), which occurs in several coal-fields, is extensively used as a pigment; and *alum* (sulphate of alumina) is obtained from many of the pyritous shales of Germany. *Ironstone*, which is found in the coal-shales either in bands, nodules, or septaria, is one of the most valuable products of the carboniferous system. It is obtained in great abundance, and being easily reduced to a metallic form by the application of coal and lime, in which the system abounds, it may be said to form one of the prime elements of our country's mechanical and commercial greatness. About two millions of tons are annually manufactured in Britain for the fabrication of the innumerable machines, utensils, and implements to which cast-iron, malleable-iron, and steel, are respectively applied. But notwithstanding the great value of these rocks and metals, they do not equal in importance those strata of *coal*, which form the main distinguishing feature of the system. The varieties principally used in Britain are caking, splint, cubic, and cannel coal; anthracite is that mainly employed in the United States; lignite and brown coal in Germany; and jet wherever it can be obtained, for the manufacture of ornaments. Coal, of which we have historical notice so early as the beginning of the twelfth century, is justly regarded as the main support of the whole system of British production; it fuses the metals, produces steam which sets machinery in motion, yields gas for light, heats our apartments, prepares our food, and, in short, renders all the resources of nature fit for civilised use. The annual consumption of coal in the British empire is estimated at about thirty millions of tons; and the export at from three to four millions. At this rate of consumption, fears have been entertained that our coal-fields would speedily be exhausted; and these fears, considering that the deposit is limited, are not altogether

without foundation. However, calculating the amount of unwrought coal in South Wales, in the middle and northern districts of England, and in the Lowlands of Scotland, and making allowance for more perfect systems of mining, and more economical modes of burning, it is estimated that, at the present rate of consumption, there is coal sufficient to meet the demand for 2000 years.

EXPLANATORY NOTE.

CARBONIFEROUS (Lat., *carbo*, coal, and *fero*, I bear)—coal-bearing or coal-yielding; applied to that system of strata from which the chief supplies of coal are obtained.

SUB-CRYSTALLINE—less than crystalline, or not distinctly crystallised. In geology, the prefix *sub* is often used in this sense; thus we say *columnar* basalt, when the columns are distinct and regular in shape, and *sub-columnar*, when the mass presents traces of an irregular columnar structure.

ENCINITE.—In many instances, the calcareous matter of the encrinite has been dissolved, so as to leave a screw-like cast of the imperforation and jointings. These casts are known by the vernacular names of *screw-stones* and *pulley-stones*; just as *turbinolæ* (fig. 2, p. 87) are called by quarrymen *pipe-heads*, and the smaller stalks of encrinites *pipe-shanks* or tubes. Separate pieces of the stalks are known in the north of England as *St Outhbert's beads*, from a legend alluded to by Sir Walter Scott in the following lines:—

—————On a rock, by Lindisfarne,
St Outhbert sits, and toils to frame
The sea-born beads which bear his name.

From the wheel-like shape of the pieces which compose the stem of the encrinite, they are sometimes technically termed *entrocki* (*trochus*, a wheel), and the limestone through which they are scattered *entrockal limestone*. This term, however, is principally applied to the pieces of the minutest stems.

LIMESTONE CAVERNS.—Caves and fissures present themselves in all rocks which have been subjected to the influence of subterranean movements, or to the eroding power of water; and may thus occur either in igneous rock, as Fingal's Cave in Staffa, or in sandstone, as the caverns of Arbroath. It is, however, in limestone that the most celebrated caves and grottos are to be found; indiscriminately in the mountain, magnesian, or oolitic beds, but on a scale of far greater splendour and magnificence in the former. Those of Derbyshire, Mitchelston in Ireland, Paros and Antiparos in the Archipelago, Australia, &c. are examples of this class, and have been formed partly from fissures caused by igneous movements, and partly by the eroding influence of springs and subterranean streams. The joints and divisional planes which so numerously intersect the mountain limestone, no doubt greatly facilitate these excavating operations.

ANTHRACITE (Gr., *anthrax*, coal)—a variety of coal almost wholly deprived of its bitumen. It may be regarded as a natural charcoal formed by subterranean or by chemical heat. Common bituminous

coal is often found converted into anthracite by effusions of igneous rock ; and this fact suggests the idea that all deposits of the kind have been similarly produced. The most extensive fields of anthracite are in Pennsylvania and the bordering states of North America.

BITUMENS OF THE CARBONIFEROUS SYSTEM.—Besides the many varieties of coal, which are bitumens mingled more or less with earthy impurities, there are other bituminous substances derived from the system. Naphtha, petroleum, mineral pitch, and asphalt, ooze out by rents ; mineral caoutchouc (*elaterite*, or elastic mineral pitch) is found in crevices of the limestone ; and a number of mineral resins and fats—such as common mineral resin, sphero-resinite (globular drops of mineral resin), mellite (crystallised resin or honeystone), Hatchetine, (mineral tallow), &c.—are obtained in small quantities. Carburetted hydrogen (fire-damp) and carbonic acid gas (choke-damp), both so fatal to miners, seem to be evolved from the coal beds after the same manner as several of the above-named products.

COPROLITES (petrified excrements) are found in all the systems of the secondary and tertiary epochs. They are chiefly the voidings of fishes and sauroid animals, and yield unequivocal evidences of their origin in containing scales, bones, and other fragments of the creatures on which these voracious animals preyed. Many specimens of coprolite retain on their external surfaces the convolutions and corrugations of the intestines ; and masses of it have been found *in situ* within the ribs of ichthyosauri.

NEW RED SANDSTONE SYSTEM.

205. *After the deposition and upheaval of the carboniferous system*, a new era occurs in the history of the globe. Overlying the coal measures in some places conformably, and in others not, there appears a set of red sandstones, variegated (yellow, purple, and greenish) shales, thick-bedded magnesian limestones of a cream colour—all of which present an aspect not to be mistaken for any previous system of strata. As to their organic remains : there are a few species of marine zoophytes, shells, and fishes, but scarcely a trace of vegetation, showing that the conditions which gave birth to the exuberance of terrestrial plants during the coal era had undergone an extensive and peculiar change. To these red sandstones, magnesian limestones, and mottled shales, the term *New Red Sandstone System* has been applied, in contradistinction to the Old Red which underlie the carboniferous strata ; and this term we adopt in preference to those of *Poikilitic* (Gr., *poikilos*, variegated) and *Saliferous* (salt-yielding), which are in use by some geologists.

206. *The composition of the New Red Sandstone* may be said to be arenaceous, argillaceous, calcareous, magnesian, and saline. The arenaceous members are chiefly reddish sand-

stones of various fineness, from a hard quartzose grit to a brecciated conglomerate. Few of them are laminated or micaceous, and the thicker beds often present curious spherical concretions of a harder texture, containing some foreign substance as a nucleus. The grains of the sandstones are of a clear quartz, merely coloured externally by a coating of the red oxide of iron, as if the debris of the rocks from which they were derived had been deposited in ferruginous waters. The *argillaceous* members are usually called "marls," from the fact of their often containing a little calcareous matter, and being less laminated in structure than the coal shales. They are generally red; but are sometimes mottled purple, yellow, and green (called variegated marls), and contain irregular beds and plates of gypsum (sulphate of lime). The *calcareous* members vary from an almost pure carbonate of lime to an admixture of carbonate of lime and carbonate of magnesia—thence called *Magnesian Limestone*. They vary in colour from an ash-gray to a cream-yellow; are sometimes finely laminated; at other times granular and crystalline, and in this state called *dolomite*, after M. Dolomieu. Frequently, a layer exhibits a cellular or vesicular texture, the walls of the cells being sparry, and the cells themselves filled with loose powdery limestone. This cellular structure is abundant in the magnesian limestone of Durham, and has received various terms from the shape of the cells; as *honey-combed*; *botryoidal*, composed of little spherical concretions like a bunch of grapes; and *mammillary*, when the concretions assume an elongated or pap-like shape. These concretionary and cellular forms are said to be *coralloidal*—that is, like to corals in shape; but they have nothing to do with organic structure, being merely the result of chemical or mechanical aggregation. The *saline* members are chiefly rock-salt, which occurs in white crystallised masses, or reddened by the argillaceous sediment among which it occurs. Salt springs abound in the new red sandstone, partly from the shales being all more or less impregnated with salt, and partly from the decomposition of the rock-salt itself. Gypsum occurs among the marls either in films or foliated fragments, the latter variety being the *selenite* of mineralogists; and oxide of copper is the green colouring matter of the shales.

207. *The order of succession among the members of the new red sandstone is not very regular or persistent.* In England, the lower part of the series consists chiefly of red sandstones and grits, the middle of magnesian limestones and gypseous marls, and the upper portion of variegated sandstones and marls, enclosing local deposits of gypsum and rock-salt. On

account of this triple succession, Professor Sedgwick has divided the system into the following groups :—

Groups.	Description.
UPPER.	7. VARIEGATED MARLS—red, with bluish, greenish, and whitish laminated clays, or marls holding <i>gypsum</i> generally, and <i>rock-salt</i> partially (as in Cheshire). Included in these marls are certain beds of gray and whitish sandstones.
	6. VARIEGATED SANDSTONES—red sandstones with white and mottled portions, the lower parts in some districts pebbly.
MIDDLE.	5. LAMINATED LIMESTONES of Knottingley, Doncaster, &c. with layers of coloured marls.
	4. GYPSEROUS MARLS—red, bluish, and mottled.
	3. MAGNESIAN LIMESTONE—yellow and white ; of various texture and structure ; some parts full of fragmentary masses.
LOWER.	2. MARL SLATES—laminated ; impure calcareous rocks of a soft argillaceous or sandy nature.
	1. RED SANDSTONE—with red and purple marls, and a few micaceous beds. The grits are sometimes white, or yellow ; and pebbly. When conformable, this sandstone occasionally passes into the coal measures on which it rests.

It must not be supposed, however, that the system always forms so complete a section ; for in some places the gypseous marls predominate, in others the magnesian limestone, while in several a mass of redstones, with subordinate layers of coloured shales, represent the whole system. The following table shows how the deposit occurs in Germany, England, and France ; from which the student may also learn the important fact, that it is by general types, and not by any conventional series of strata, that systems are to be identified in different countries :—

GERMANY.	ENGLAND.	FRANCE.
Keuper Marls and Grits.	Variegated Marls and Grits.	Marnes Irisées.
Muschelkalk.	Variegated Sandstone.	Muschelkalk.
Bunter Sandstein.	Upper Limestone.	Gres Bigarré.
Stinkstein ; Rauwacké.	Gypseous Marls.	_____
Gypseous Marls.	Magnesian Limestone.	_____
Zechstein.	Marl Slate.	_____
Kupfer Schiefer.	Lower Red Sandstone.	Gres Rouge.
Rothe-todte-liegende.		

208. "*The organic remains* of this system," says Professor Phillips, "though few in number, are exceedingly interesting to the naturalist and geologist, from the strong testimony they offer of the successive changes of the living creation, according to the new circumstances of the land and sea. The

fossil plants, shells, fishes, and reptiles of this system, appear to partake both of the character of those in the older carboniferous, and the newer oolite deposits. Calamites, like those of the coal formation, are mingled with cycadeæ, resembling closely those of the oolites. Productæ, so common in mountain limestone, occur in the zechstein with terebratulæ, like those of the lias and oolites. Fishes of the genus *paleoniscus* here occur for the last time, in ascending the series of strata; and here, perhaps, for the first time we have remains of oviparous quadrupeds—the *protosaurus* and *phytosaurus*." Exhibiting this transition from one system of life to that of another, the new red sandstone has been regarded as the boundary between the LOWER and UPPER SECONDARY STRATA—the old red sandstone, mountain limestone, coal measures, and new red sandstone, belong to the *lower* or older secondary formation; and the lias, oolite, and chalk, to the *upper* or younger secondary.

209. *The number of fossil species* hitherto detected in the new red sandstone of England amounts to fifty or thereby, while fully thrice that number has been found in France and Germany. These consist of traces of marine plants, a few terrestrial plants, several zoophytes, one species of crinoidea, about two dozen species of bivalves, one chambered shell, several fishes, the mutilated skeletons of two sauroid animals, and the traces of footsteps, called *ichnites*, from the Greek *ichnon*, a footmark. Like the vegetation of the coal era, the plants of the new red sandstone are chiefly vascular cryptogamia; the corals, bivalves, and fishes, are apparently the same; and it is only in the chambered shells, and in the sauroids, that new types are presented. Altogether, the system seems to have been deposited under circumstances peculiarly unfavourable to animal and vegetable life; at least few organic exuvie are to be met with in its strata.

210. *The igneous rocks associated with the system* are chiefly dykes of greenstone, which pass indiscriminately through the magnesian limestone, coal measures, and old red sandstone. These dykes belong to no definite volcanic era, but seem to have been formed by minor forces acting over limited extents. The granitic rocks of the primary period, as well as the traps of the old red sandstone and carboniferous measures, establish themselves in well-marked and characteristic ranges; while the igneous rocks of the new red sandstone, lias, and oolite, are mere local effusions limited to dykes and partial upheaves. In their mineral character, these rocks differ little from the traps of the coal measures—consisting chiefly of greenstone, pitchstone, and clay-stone porphyry.

211. *The extent of country over which this system is spread* is not well ascertained. Slight traces of it occur on the western coast and islands of Scotland, and on the Fife shores of the Forth; it occupies a wider area in the basin of the Solway and its tributaries; spreads largely over the central districts of England from the Tyne southwards; and is found in the north of Ireland. Extensive areas are covered by it in the continent of Europe—in France, Germany, Poland, along the flanks of the Alps, in Austria, and between the Volga and the Ural mountains; and, according to Professor Hitchcock, it is spread over considerable spaces in some of the river valleys of the United States.

212. *The physical aspect of new red sandstone districts*, as may be conjectured from the limited force of the igneous rocks, is rather flat and gentle. There are no picturesque crags, mountain ranges, or deep ravines to diversify the scenery; which consists of rounded terraces of magnesian limestone, and level expanses of red sandstone and shales, here and there dotted with a gentle eminence of limestone or gravel. Over the limestone the sward is thick and verdant, and the soil above the red sandstone is of average fertility; but where the retentive shales spread out in flat hollows, they form the basis of extensive morasses—as, for example, those of south Lancashire, in England.

213. *The minerals of commerce derived from the formation* are not numerous—the most important being magnesia and rock-salt. The magnesian limestone, when reduced to quick-lime, is employed with effect on certain soils; it furnishes the builder with mortar; and yields, under chemical treatment, the magnesia of the apothecary. In some localities it furnishes a beautiful and durable building-stone; that of Bolsover moor, in Derbyshire, being the material employed in the construction of the new houses of Parliament. Some of the limestone schists are also suitable for lithographic purposes, the admired German blocks being chiefly derived from this source. Gypsum is obtained from the marls of the series, which also yield the main supply of rock-salt in various parts of the world—such as Cheshire and Worcester in England, in Spain, Poland, Germany, and Austria. This salt occurs in beds or irregular masses, from 10, 20, or 30 feet, to 120 feet in thickness; is of various degrees of purity and colour. Sometimes it contains scarcely two parts in the hundred of foreign matter, at others it is of a red colour, and mixed to the extent of half its bulk with earthy impurities. *Brine, or salt-springs*, which often issue from this deposit, contain from 20 to 30 per cent. of salt, and are doubtlessly derived from the solution of the solid

masses by subterranean waters. The *kupfer-schiefer* of Germany is worked to some extent as an ore of copper; but no other metal is derived from the system.

214. *The formation of rock-salt* is a subject, in connexion with this system, which has much engaged the attention of speculative geologists. The sandstone and marls with which it is associated are evidently derived from deposition in water; but the irregularity of the salt beds, the fact of their occurring in masses of vast thickness, and the soluble nature of the compound, all point to a somewhat different origin. At present, salt lakes and superficial accumulations of salt occur in various parts of the world, and these have furnished data for reasoning as to the saliferous deposits of earlier eras. Salt lakes are chiefly derived from salt springs, and being subjected to the vaporising influence of the sun, which carries off only *fresh* vapour, their waters become in time saturated with saline matter. But water can hold only a fixed amount of salt in solution; and so soon as this amount is attained, the salt begins to fall to the bottom by its own gravity. In the course of ages, these layers will form a thick bed, interstratified, it may be, with mud, or other earthy sediment; and if the lake should be ultimately dried up, the salt will constitute a deposit something analogous to the rock-salt of the new red sandstone. Such is the process which some geologists have advanced to account for the formation of rock-salt—supposing that portions of the seas of deposit were occasionally cut off from connexion with the main ocean, and subjected to a rapid evaporating power, without receiving fresh accessions of water. The limited extent of rock-salt basins seems to favour such a theory; but when we consider the frequency of disturbance by volcanic forces in earlier ages, and the fact of many of these deposits occurring near to, or in connexion with, mountain elevations, it is more than probable that igneous action, as well as a high atmospheric temperature, had to do with their formation. If such were the origin of rock-salt, it must have been formed during the deposition of other systems than the new red sandstone; and this geological research has confirmed; for although the most extensive accumulations do occur amid the sandstones and shales of the system under review, still, deposits of considerable thickness are found in connexion with oolite, green-sand, and tertiary rocks, while numerous salt springs issue from the carboniferous strata.

215. *The formation of magnesian limestone* has also given rise to several theories. Minute quantities of magnesia occur variously combined in the crust of the earth; but only in the limestones of this system is it sufficiently developed to consti-

tute a peculiar and distinguishing feature. The most prevalent hypotheses advanced to account for this peculiarity are—first, that the carbonate of magnesia was deposited at the same time as the carbonate of lime; and, second, that it was subsequently injected in the form of gaseous vapour. Neither hypothesis seems to account for all the phenomena presented; although the former is that which admits of most extensive application.

EXPLANATORY NOTE.

NEW RED SANDSTONE SYSTEM.—In some recent works, it has been attempted to arrange the rocks of this system, as developed in England, under two grand divisions; the first including the lower new red sandstone and magnesian limestone, and the second the variegated sandstones and gypseous marls. This arrangement has been made in order to facilitate comparison with the contemporaneous systems of continental and eastern Europe. In Germany and the neighbouring countries the former division corresponds with the *Rothe-todte-liegende*, and the latter with what is now generally known as the *Triassic system* (so called from its being readily divisible into three groups—the Bunter Sandstein, Muschelkalk, and Keuper Marls). To the rocks of eastern Europe, which seem contemporaneous with the new red sandstone, Mr Murchison has applied the term *Permian system*, from their being widely developed in the ancient kingdom of Permian, which extends for several hundred miles along the western flanks of the Uralian chain, and thence westward to the river Volga.

ZECHSTEIN (mine-stone)—so called from its containing a deposit (*Kupfer-schiefer*, or copper-slate) which is worked as an ore of copper; and the underlying sandstone has received the name *Rothe-todte-liegende* (red dead-lier), because it is of a red colour, is *dead* or worthless as far as any metallic ore is concerned, and *underlies* the real metallic deposit. The other terms, *Stinkstein*, *Muschelkalk*, *Gres Rouge*, &c. require no translation.

ICHNITES, or fossil footsteps, present a curious example of the means by which geologists are enabled to decipher the history of the earth. Most people must have observed how distinct the impressions of the feet of birds and other animals are often left on the mud or sand of ebbing rivers. If this mud should remain exposed to the sun and air till sufficiently dried, and then be overlaid by some new sediment, the impression of the foot will form a mould into which the new matter will be deposited. Should the two layers ever be consolidated into stone, on being separated, the one would present a *mould*, and the other a *cast* of the footsteps; and this is precisely what takes place among the strata of the earth's crust. Fossil footsteps have been discovered in the new red sandstone of Cocklemuir in Dumfriesshire, and in that of Hildburghausen in Saxony, supposed to be those of reptiles; hence termed *sauroidichnites*. Others have been detected in the sandstones of Connecticut, United States, and ascribed to gigantic birds allied to the ostrich family; consequently called *Ornithichnites*, from the Greek words *ornis*, a bird, and *ichmon*, a trace or footprint. To these Professor Hitchcock adds a third class, *tetrapodichnites*, or the footsteps of some unknown *four-footed* animal.

OOLITIC SYSTEM.

LIAS, OOLITE, AND WEALDEN GROUPS.

216. *After the deposition of the new red sandstone*, a further change was effected upon the general conditions of the globe, so as to produce not only an entirely different set of strata, but also different races of plants and animals. In most districts, the red sandstones and magnesian limestone were upheaved, to form new land, while portions of the former dry land were submerged beneath the ocean. By this process of elevation and depression the courses of previous rivers would be altered, former seas circumscribed and rendered more shallow, plants and animals subjected to a new distribution, and thus a different set of deposits would necessarily ensue. Instead of magnesian rocks, we have dark argillaceous and oolitic limestones; for variegated saliferous marls, we have blue pyritous clays; and instead of red and mottled sandstones, yellow calcareous grits. All this points to a new epoch in the terrestrial conditions of the world; and to the system of strata thus deposited geologists apply the term *oolitic* (Gr., *oon*, an egg, and *lithos*, a stone), from the resemblance which the texture of many of the beds bear to the roe or eggs of a fish. Oolite, or *roestone*, is an aggregate of rounded calcareous particles, varying from the size of a millet-seed to that of a marble—the smaller being almost perfectly spherical, the larger irregular, and having their interstices filled with calcareous matter or broken shells. The system in England comprises three well-defined groups; namely, the Lias, the Oolite proper, and the Wealden clays.

217. *The Lias*, the lowest group in the system, is composed of dark argillaceous limestones, bluish clays, and shales. The clays in general predominate, and occur with interstratified limestones; they contain occasional layers of jet or other coal: ironstone in septaria is not unfrequent; and many of the shales abound in bitumen and iron pyrites. As indicated by the name (*lias*, corruption of *layers*), the limestones are finely stratified, and have evidently been deposited in tranquil waters. Most of the shales, in addition to their bituminous and pyritous qualities, are impregnated with muriate of soda (common salt), and with the sulphates of magnesia and soda: and Mr Bakewell states that it is not uncommon, after wet weather, for the Yorkshire sea-cliffs, which are composed of these shales, to ignite spontaneously, and burn for several

months. *The Oolite* is more varied in its composition, consisting of oolite limestones, calcareous grits, or conglomerates, yellowish sands, and clays all more or less calcareous. The peculiar rounded grains which constitute the oolitic texture, consist either entirely of lime, or of an external coating of lime, collected round minute particles of sand, coral, shells, &c.; the grits are composed of sand, lime, fragments of shells and corals; and many of the clays present the same brecciated texture. *The Wealden group* (from the *wealds* or *wolds* of Kent and Sussex, where the deposit prevails) consists of beds of bluish clay, argillaceous limestones, impure oolites, and ferruginous sandstones. Nodular ironstone occurs in the clays, and beds of pisiform (Lat., *pisum*, a pea) iron-sand are occasionally met with, while oxide of iron is more or less diffused through the whole group. Fossil plants are abundant; and, as may be expected from this circumstance, local traces of coal are not unfrequent.

218. *Taking the whole system into account*, it is apparent that calcareous and argillaceous compounds prevail; indeed it may be said to be an argillo-calcareous deposit, including subordinate layers of sandstone, bands of ironstone, and traces of coal. Among the lias strata, dark hues prevail; among the oolite, cream-yellow and ochraceous colours; the clays of the wealden are dark blue, while its other beds partake of a ferruginous tint.

219. *With regard to the succession among the strata*, no very regular order is observed; though no fact in geology is better established than the supraposition of the lias, oolite, and wealden, as above-described. The lias is the most extensive and persistent of the three groups, and seems to have been deposited over wider areas; the oolite is less persistent, being often interrupted by changes from sandstones to brecciated grits, and from grits to oolitic limestones; and the wealden is the least extensive, being justly regarded as a half estuary half marine deposit, peculiar to certain districts. Taking the system as developed in England, the following is the ascertained order among the strata, between which and the contemporaneous rocks of the continent there is no essential mineral or fossil distinction:—

WEALDEN.

- { Blue laminated clays, containing concretionary ironstone and thin layers of argillaceous limestone. (The weald clay.)
- { Sands and sandstones, frequently ferruginous; beds of clay and sandy shale, all more or less calcareous. (Hastings sands.)
- { Various estuary limestones, alternating with sands and clays. (Purbeck beds.)

OOLITE.

Portland oolite ; calcareous iron sand and concretions ; and a calcareous clay, locally called " Kimmeridge clay."

Coralline oolite (coral rag) ; calcareous sands and grits ; Oxford clay, including layers of impure clayey limestone.

Oolitic and shelly strata (Cornbrash) ; forest marble ; Bath oolite ; yellow sandstones, divided by clays and calcareous sands ; marls and fuller's earth.

LIAS.

Thick beds of dark-coloured bituminous shale ; beds of pyritous clay ; and indurated lias marls.

Lias limestones and clays ; bands of ironstone ; layers of jet and lignite ; sandstones more or less calcareous.

220. *The organic remains of the oolitic system* are very numerous, and have long attracted the attention of geologists. They show a decided advance upon pre-existing races, inasmuch as insects, amphibious reptiles, and mammalia, make their appearance in the animal kingdom ; while new tribes of vegetables, such as the cycadeæ, lilacæ, &c. are added to the former Flora. The organisms of the lias, the oolite, and the lower members of the wealden, indicate the marine origin of these deposits ; those of the upper weald an estuary character, from the comminglement of fresh water with marine species. With this distinction, the Fauna and Flora of this epoch may be thus summarily detailed :—*Plants*—seaweeds ; a few equisetums ; many ferns allied to the sphenopteris, pecopteris, &c. of the coal measures ; cycadeæ, allied to the existing cycas revoluta and pine-apple ; coniferæ, resembling the yew and pine ; besides lilacæ and other undescribed genera. *Animals*—zoophytes, more like existing species than those of the mountain limestone and silurian rocks ; crinoidea, chiefly the apiocrinite and pentacrinite ; star-fishes, resembling the common ophiura and asterias ; echinida (sea-urchins), of which the cidaris is one of the most beautiful and abundant ; shell-fish, both bivalves, univalves, and chambered ; annulosa, like the common serpula and land-worm ; crustacea, resembling the lobster-tribe ; insects like the beetle and dragon-fly ; fishes belonging chiefly to the ganoidia ; reptiles allied to the tortoise, to the crocodile, and gavial of existing rivers, but differing widely in their external forms and modes of existence ; mammalia, two or three specimens of small marsupial animals allied to the opossums. In the upper or fresh-water wealden, there are no zoophytes or marine mollusca ; but there are, according to Phillips, various land plants, fresh-water bivalves and univalves, some fishes, sauroid animals, and remains of turtles, both fresh-water and marine.

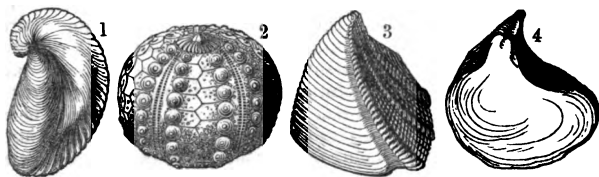
221. *The fossils most characteristic of the system are the cycadeæ, of which the stems, fruit, and leaves are found in abundance, the sea-urchins, the ammonites of various genera and gigantic size, the sauroid reptiles, the ptero-dactyles or flying lizards, the fresh-water and marine turtles, and the marsupial mammalia. The cycadeæ occur principally in the upper or fresh-water portion of the weald, intermingled with the stumps and prostrate trunks of trees. They are found most plentifully in what is locally designated the "dirt-bed" of Portland—a stratum of dark argillaceous mud, which must at one time have been the soil in which they and other vegetables flourished, but which, by a submergence of the land, was converted into the bottom of an estuary, over which other strata of clay, limestone, and sand were deposited. "At the distance of two feet," says Bakewell, "we find an entire change from marine strata to strata once supporting terrestrial plants; and should any doubt arise respecting the original place and position of these plants, there is, over the lower dirt-bed, a stratum of fresh-water limestone, and upon this a thicker dirt-bed, containing not only the cycadeæ, but stumps of trees from three to seven feet in height, in an erect position, with their roots extending beneath them. Stems of trees are found prostrate upon the same stratum; some of them are from twenty to twenty-five feet in length, and from one to two feet in diameter. The following section of a cliff in Dorset exhibits very clearly proofs of the alternation from*



a a a, Portland Stone (marine formation); *b*, Dirt-bed, consisting of black mould and pebbles (temporary dry land); *c*, Burrstone, and *d*, Calcareous Slate (both of fresh-water formation).

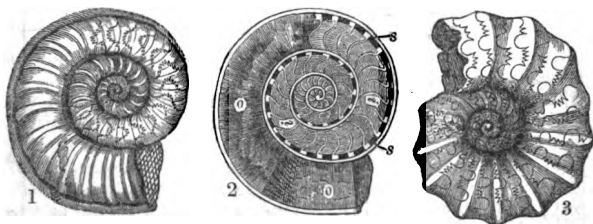
marine strata to dry land covered with a forest, and of a subsequent submergence of the dry land under a river or lake which deposited fresh-water limestone."

222. *Of the radiata, mollusca, and crustacea of this era, it may be observed, that while they differ essentially from those of the older secondary strata, they approximate in form to existing races. The gigantic and prolific crinoidea of the mountain limestone had disappeared, and been succeeded by a few dwarfish specimens of apiocrinite and pentacrinite; while the cidaris (see fig.), clypeus, and other echinida (sea-urchins), attest a higher degree of organisation among radiated animals. Among the shell-fish, the gryphæa, trigonia, ostrea, and ammonite, are the most characteristic—hundreds of species of*



1. *Cidaris intermedia*; 2. *Gryphæa incurva*; 3. *Trigonia costata*; 4. *Ostrea deltoidea*.

the latter having left their remains in the most perfect state of preservation in the shales and limestones of the lias. The ammonite (of which two species, and a section of the interior, is figured below) receives its name from its resemblance to the curved horn on the head of the statue of Jupiter Ammon. It



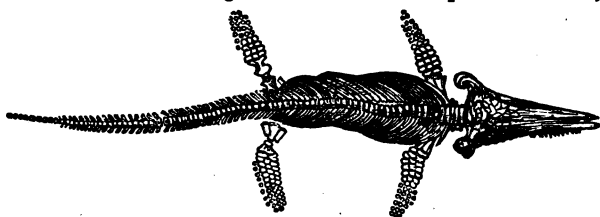
1. *Ammonites obtusus*; 2. Section of *Ammonites obtusus*, showing the interior chambers and siphuncle; 3. *Ammonites nodosus*.

was a chambered shell belonging to the *cephalopodous* division of mollusca—that is, having its organs of motion arranged round the head; and had many congeners in the euomphalus,

nautilus, orthoceratite, hamite (hook-shaped), scaphite (boat-shaped), baculite (staff-shaped), and other many-chambered shells. It is one of the most widely-distributed molluscs in the secondary strata, and is found of all sizes, from that of a pin's head to three or four feet in diameter. The economy of the ammonite destined it in general to live at the bottom of deep waters, but to be able to rise at pleasure to the surface. For this purpose the outer chamber (*o o*) of the wreathed shell was fitted for the reception of the animal, while the interior chambers (*i i*) were hollow, so as to make the whole structure nearly of the same weight as the element in which it moved. Through all of these chambers an elastic tube passed by means of a pipe or siphuncle (*s s*), the tube being in connexion with the cavity of the heart, which, under ordinary circumstances, was filled with a dense fluid. When alarmed, or wishing to descend, the animal withdrew itself within the outer chamber, and the pressure upon the cavity of the heart forced the fluid into the siphuncle, so as to increase the gravity of the shell, by which means it readily sunk to the bottom. On the other hand, when wishing to ascend, it had only to project its arms, and the fluid, being freed from the pressure, returned from the siphuncle to the cavity of the heart, thus restoring the whole structure to its ordinary floating gravity. As the pressure of water at the bottom of the sea would break the plates of any ordinary shell, as it does a bottle when it is lowered to a great depth, the shell of the ammonite has been strengthened by a curious kind of internal arch-work, so as to be able to resist the weight of the incumbent fluid. This arch-work so completely meets all human ideas of ingenious contrivance for the purpose which it was destined to serve, as to form one of the most striking examples of that adaptation of means to ends which prevails throughout the works of nature, and which is so well fitted to impress the conviction of a great designing First Cause.

223. *The insects, fishes, and reptiles of the oolitic system* have greatly attracted the attention of naturalists and geologists; and, as might be expected from remains so obscure, have given rise to much diversity of opinion. The insects discovered in the slaty limestones of the true oolite at Solenhafen in Germany, and Stonesfield in England, somewhat resemble the dragon-fly and serricorn beetles of the present day. The fishes present the enameled scale and unequally-lobed tail of the cartilaginous order, and find a distant analogue in the existing *cestracion* of the Australasian seas. It was stated, that the bones and teeth of reptiles had been found in the marls of the new red sandstone; but in the lias and the strata

above it, the exuviae of these animals are so abundant, and of such vast size, that the epoch in which these strata were deposited has not unaptly been termed "the age of reptiles." Of these there are terrestrial and marine chelonida (tortoises and turtles); lizards, whose arms and legs were fitted with a filmy membrane, like bats, to enable them to fly (ptero-dactyles); amphibious saurians, like the gavial and crocodile; and water saurians, to which there is now no existing analogy. Of these sauroid or lizard-shaped reptiles, the ichthyosaurus and plesiosaurus are most abundantly disseminated through the upper secondary formations. The general form of the ichthyosaurus (Gr., *ichthys*, a fish, and *saurus*, a lizard) appears from its skeleton (see fig.) to have been not unlike that of a crocodile, with the substitution of paddles for feet. The head is lengthened into a narrow pointed muzzle,



Skeleton of *Ichthyosaurus communis*.

and the jaws armed with sharp and formidable teeth. The skeleton of the *I. tenuirostris* (slender-muzzle) usually measures about four feet in length; but detached remains of other species have been found, indicating a length of twenty or even thirty feet. The plesiosaurus (so called from its greater affinity to the lizard tribe than to fishes) was distinguished by the extraordinary length of its neck, which, in the commonest species (*P. dolichodeirus*, or long-necked), occupies nearly half the entire length of the animal. The head is very small in proportion, and the tail is short, stout, and pointed. The vertebrae of the neck exceed in number those of any other animal known. It is conjectured by Mr Conybeare, by whom the first scientific investigation of this saurian was made, that, as it breathed air, and had frequent need of respiration, it generally swam upon or near the surface of the water, arching back its long neck like the swan, and plunging it downwards at the fishes that passed within its reach. Its length seems to have been from ten to fifteen feet. From the nature of their extremities, both the ichthyosaurus and plesio-

saurus must have moved with great difficulty upon land, and seem principally to have inhabited the waters. Besides these, geologists enumerate many other species of saurians—aquatic, amphibious, and terrestrial; such as the *megalosaurus* (great saurian), *geosaurus* (land saurian), *hylaesaurus* (forest saurian), *teleosaurus* (perfect saurian), &c.

224. *Respecting the mammalia of this era*, no very satisfactory data have yet been procured, the only evidence being two or three lower jaw-bones from the slaty limestone of Stonesfield. Though some French geologists have attempted to ascribe a sauroid character to these remains, it is the opinion of Cuvier, Dr Buckland, and Professor Owen, that they belong to true *didelphys* (*dis*, two, *delphys*, wombs) animals; that is, double-wombed, or marsupial creatures, like the opossum and kangaroo. Should this be the case—and comparative anatomy is too unerring in its deductions to admit of any doubt—then in the upper oolite are we for the first time made acquainted with mammalia in the history of creation. “The close approximation of these fossil animals,” says Professor Owen, “to marsupial genera, now confined to New South Wales and Van Diemen’s Land, leads us to reflect upon the interesting correspondence between other organic remains of the British oolite, and other existing forms now confined to the Australian continent and adjoining seas. Here, for example, swims the *cestracion*, which has given the key to the nature of the palates from our oolite, now recognised as the *teeth* of congeneric gigantic forms of cartilaginous fishes. Not only *trigonia*, but living *terebratulæ* exist, and the latter abundantly in the Australian seas, yielding food to the *cestracion*, as their extinct analogues doubtless did to the allied cartilaginous fishes called *acrodi* and *psammodi*, &c. Auracarie and cycadeous plants likewise flourish on the Australian continent, where marsupial quadrupeds abound, and thus appear to complete a picture of an ancient condition of the earth’s surface, which has been superseded in our hemisphere by other strata, and a higher type of mammalian organisation.” Professor Phillips remarks to the same effect—“It is interesting to know that the earliest mammalia of which we have yet any trace were of the marsupial division, now almost characteristic of Australia, the country where yet remain the *trigonia*, *cerithium*, *isocardia*, *zamia*, tree-fern, and other forms of life so analogous to those of the oolitic periods.”

225. “*During the oolitic period*,” continues the latter authority, “the arctic land was covered by plants like those of hot regions, whose vegetable remains have locally generated coal-beds, adorned by *coleopterus*, *neuropterus*, and other insects,

among which the flying lizard (pterodactylus) spread his filmy wings. The rivers and shores were watched by saurians more or less amphibious (megalosaurus, iguanodon), or tenanted by reptiles which by imaginative men have been thought to be the originals of our gavials and crocodiles, while the sea was full of forms of zoophyta, mollusca, articulosa, and fishes. Undoubtedly the general impression, gathered from a survey of all those monuments of earlier creations, is, that they lived in a warm climate; and we might wonder that the result of all inquiry has shown no trace of man or his works, did we not clearly perceive the oolitic fossils to be all very distinct from existing types, and combined in such different proportions, as to prove that circumstances then prevailed on the globe materially different from what we now see, and probably incompatible with the existence of those plants and animals which belong to the creation whereof man is the appointed head."

226. *The igneous rocks associated with the system* in England belong chiefly to the trappean order. In no case have they caused much displacement or great disturbance among the strata, being gentle outbursts of trap-tuff, or intersecting dykes of greenstone. These dykes are always connected with some volcanic axis of the carboniferous period, and seem to have been among the last upheaving efforts of the trappean era. In Caithness, granitic rocks pass through the oolitic strata, but with this exception—the igneous rocks, which have upheaved or altered the system, belong either to the latest trap, or the earliest volcanic epochs.

227. *The extent of country occupied by the oolite* is by no means extensive, though partial deposits are very generally disseminated over the globe. It is most fully developed in England, occupying the eastern sea-board from Yorkshire to Dorset; it occurs in a small patch at Brora in Sutherland, in Skye, and other of the Hebrides, and partially in Ireland and Wales. Portions of the system are also found in France and Germany; skirting the Alps; in Spain and the Balearic islands; flanking the Apennines and Atlas range; on the southern slope of the Himmalehs; but no true equivalents to the European oolite have hitherto been detected in America.

228. *Unless in England, the oolitic system is not so extensively developed as to impart any distinctive geographical feature;* and there, though pleasing, the aspect is tame compared with that imparted by the older strata. The limestones in general form rounded escarpments over the subjacent clays, "so that several longitudinal hollows and ridges undulate the area occupied by the system." None of these ridges are of great

height (400 to 600 feet), but they are dry and fertile ; and thus present an agreeable contrast with the level river valleys occupied by the lias and wealden clays.

229. *In an economical point of view*, the rocks of this system are by no means unimportant. The lias limestones generally consist of from 80 to 90 per cent. of carbonate of lime, combined with bitumen, alumine, and iron ; and when the latter mineral enters largely into their composition, they form, when burned, a lime which has the property of setting under water. The finer kinds of lias receive a polish, and are used for lithographic purposes. The lias clays are often much impregnated with bitumen and iron pyrites, and will burn slowly when laid in heaps with fagots and kindled. By this process the sulphur of the pyrites is decomposed, and combining with the oxygen of the atmosphere, and with a portion of the alumina in the shale, forms sulphate of alumina, or the *alum* of commerce. During the sulphur monopoly, several patents were obtained for the extraction of sulphur from iron pyrites (sulphuret of iron), most of which would have been profitably adopted, had the native produce of Sicily continued at the then exorbitant rate. Iron has also been extracted from the ironstone and pisiform iron-sands of the wealden group ; and jet (which is simply altered coniferous wood) occurs in the same measures. Fuller's earth, at one time so valuable in the useful arts, is found in the upper oolite in beds of great thickness. It is essentially composed of silica, alumina, and 24 per cent. of water, and, like other soft aluminous marls, possesses in a high degree the power of absorbing grease ; hence its value in cleansing and scouring woollen stuffs. Some of the oolite sandstones form excellent building material, such as those of Bath and Portland ; several ornamental marbles are obtained from the same group ; while the Purbeck beds of the wealden furnish the most prevalent paving-stones in London.

EXPLANATORY NOTE.

LIAS.—The term *Liassic* is commonly applied to this group by recent authors.

CORNBRASH is said to derive its name from the facility with which it disintegrates and yields to the plough, being, according to the provincial term, *brashy* or breaky enough to enable the plough to prepare the surface, where it prevails, for the growth of grain or *corn*.

SAUROID ANIMALS are generally classed according to their organs of locomotion ; namely, *swimmers*, or those fitted with paddles, as the ichthyosaurus, plesiosaurus, mososaurus, phytosaurus, steneosaurus, teleosaurus, saurodon, &c. ; *with limbs like mammalia*, and fitted for a terrestrial life, the megalosaurus and iguanodon ; *analogous to living amphibia*, the protosaurus, geosaurus, pleurosaurus, hylæosaurus, &c.

THE CHAMBERED SHELLS of this system include many genera, all of which are fitted with interior hollow chambers and siphuncles. The most common are the ammonite, nautilus, euomphalus, bellerophon, goniatite, hamite (*hamus*, a hook), scaphite (*scapha*, a boat), orthoceras-tite (*orthos*, straight, *keras*, a horn), baculite (*baculum*, a staff), lituite (*lituus*, an augur's rod or crosier), &c. &c. Sometimes the shelly matter of the ammonite has been entirely destroyed, leaving only a cast of the interior, each chamber in this case playing upon another by the intricate jointings of the *septa*, or divisional lines; such casts are known by the name of *ammonites catena*, or ammonite chains.

CRETACEOUS, OR CHALK SYSTEM.

230. *Immediately overlying the wealden, and forming the upper portion of the secondary formation*, occurs a set of calcareous, argillaceous, and arenaceous strata, distinguished in Europe as the Cretaceous System, from its containing the well-known mineral, *chalk* (Lat., *creta*). In this system, as stated in par. 140, the arenaceous members are no longer sandstones, but loose unsolidified sands; the argillaceous beds are generally soft and marly clays; and the calcareous, instead of compact or crystalline limestones, present that soft earthy texture which prevails in chalk. All this attests a comparative recentness of formation, apart from great pressure, long-continued chemical action, or the indurating effects of heat. The strata occupy very limited spaces, and being decidedly of marine origin, point more to detached and inland seas as the areas of their deposit, than to the shores or bays of the ocean. Being thus, as it were, a local deposit, and of a thickness not exceeding 800 or 900 feet, the chalk has been more thoroughly explored than any of the older systems, and its fossils more rigidly compared with existing species. Upon investigation, it has been found that it embraces three well-marked groups; namely, the *Green-sand*, the *Gault*, and *Chalk*.

231. *The composition of these groups* is almost sufficiently indicated by their respective terms. The *Green-sand*, which forms the lower division, is so named from its green colour, which it owes to a chloritous silicate of iron. These sands, however, are not uniformly green, but partake of ochraceous and yellow tints; they present various degrees of fineness; and not unfrequently contain cherty bands, irregular deposits of fuller's clay, and ochre. In England, they are usually divided into the Lower and Upper green-sands, because of a bed of soft bluish marly clay which occurs about the middle of the group. Regarding this bed as subordinate, the green-sand is easily distinguished from the rest of the system by its arenaceous composition and greenish hues. The *Gault*, or

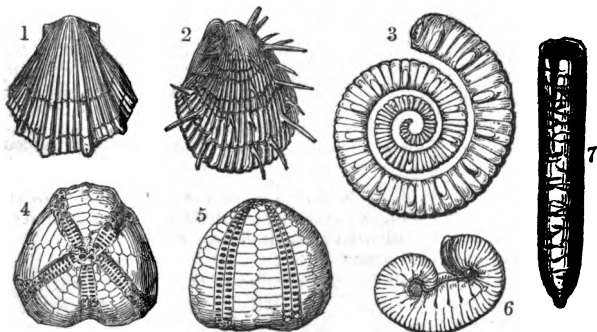
golt (a local term), overlies the green-sand, and is not of great thickness, nor very regular in its occurrence. It is a bluish chalky clay, which effervesces strongly on the application of acids; it is interstratified with layers of green-sand, and holds irregular balls of argillaceous ironstone and iron pyrites. In some districts the gault assumes a reddish tint, from the iron it contains; but in other respects its composition is very persistent. The *Chalk*, which forms the upper group of this system, is too well known to require description. It consists chiefly of carbonate of lime, has an earthy texture, and is so soft as to yield to the nail. Though generally white, it sometimes passes into a dusky gray, or even red colour, as in the north of England; and where it has come in contact with igneous rocks, it is indurated, and of a crystalline texture, like that of statuary marble. In England, the chalk strata average from 600 to 800 feet in thickness, and are usually divided into the lower and upper beds; the former being more compact, of a dusky white varied with green grains, and containing few flints—the latter being a soft white calcareous mass, with chert nodules and regular layers of flints. Traces of stratification are scarcely distinguishable in the mass of the chalk, but are clearly evinced by the lines of flints and other nodular concretions. In some of the continental chalks, carbonate of magnesia prevails to the extent of 8 or 10 per cent., giving to such beds a still more earthy texture.

232. *The order of succession among the strata* is such as has been shown above; but, to render it more distinct, we may transcribe the following sectional detail of the system as it occurs in the south of England:—

CHALK.	UPPER CHALK—usually a white soft calcareous mass, with chert nodules at regular intervals, and layers of flints.
	LOWER CHALK—harder and less white than the upper; sometimes varied by green grains; generally with fewer flints. (Red in the north of England.)
GAULT.	GAULT, OR CHALK MARL—beds of bluish laminated clays, highly calcareous, with layers of green-sand, and ferruginous nodules.
GREEN-SAND.	UPPER GREEN-SAND—a mass of sands, occasionally indurated to chalky or cherty sandstone, of green or grayish-white colour, with nodules of chert.
	Soft bluish clay, with green grains. LOWER GREEN-SAND—a considerable mass of green, or ferruginous sands, with layers of chert; local beds of blue clay; rocks of chalky or cherty limestone; and deposits of ochre and fuller's earth.

All the members detailed above do not occur in other cretaceous districts ; for example, there is no green-sand in the north of England ; no chalk along the Carpathians ; no gault in America ; while in South America the system is represented by impure chalky beds of no great thickness.

233. *The organic remains found in the system are eminently marine.* There are very few *plants*, and these chiefly of marine types, such as algæ, confervæ, and other sea-weeds. Rare fragments of ferns, cones of coniferous trees, cycadites, and dicotyledonous wood, have been detected in the green-sand ; and a patch of *lignite* is said to occur in the lower chalk, near Rochelle in France. Respecting this deposit, M. Brogniart thinks it may have been formed by the local submergence of a *peat moss* ; but generally speaking, there is no formation so destitute of terrestrial organisms as the chalk. Among the *animal remains*, sponges, corals, star-fishes, annulosa, univalve, bivalve, and chambered mollusca, crustacea, fishes, and reptiles, are found in abundance ; but, with one exception, *mammalia* are not known in the cretaceous rocks. The same races which appeared in the oolite appear also in the chalk, but of very different genera ; so much so, that it has been observed that the cretaceous system contains genera never found in any rocks more ancient or more modern. "There



1. *Pecten quinque-costatus* ; 2. *Plagiostoma spinosum* ; 3. *Hamites intermedius* ; 4. *Spatangus cor-anguinum* ; 5. *Galerites albogalerus* ; 6. *Scaphites striatus* ; 7. *Belemnites mucronatus*.

appears no sufficient evidence," says Professor Phillips, "in the fossils of this system to justify any positive inference as to the character of the climate then prevailing in the northern zones ; but we may be sure that the sea was very little dis-

turbed by inundations from the land, otherwise ferns and other plants, and not fuci, would have been found in the sandy strata." It is true that the evidence respecting the climate, and other conditions of the cretaceous era, is still imperfect; but the recently-discovered remains of the highest order of mammalia (quadrumana, or monkey tribe) point to a tropical climate; and this fact, taken in conjunction with the occurrence of cycadites, seems to establish a temperature little different from that which prevailed during the wealden epoch. The foregoing engraving represents a few of the more characteristic fossils belonging to the system.

234. *Igneous rocks* are nowhere associated with the chalk in England; but basalt and other traps break through and overlies the strata in the north of Ireland—the Giant's Causeway presenting one of the finest examples of this connexion. In the Pyrenees, cretaceous strata are said to be in contact with granitic rocks; but, generally speaking, the system has escaped with fewer displacements by igneous agency than any of the earlier formations. As has been stated, where chalk comes in contact with igneous discharges, the heat has rendered it hard and crystalline like primary marble. The same effects have been produced by enclosing pounded chalk in an iron tube, and subjecting it to the heat of a furnace.

235. *The geographical extent of the system* is limited, when compared with earlier formations. It is pretty extensively developed in the south and south-east of England, filling up the hollows and basins left by the oolite and lias. It appears in the north of Ireland overlaid by basalt and other trap rocks; but is unknown in Wales or in Scotland. It is spread over wide areas in France and Germany; and is found about Dresden, in the Alps, Carpathians, and Pyrenees. According to Professor Rogers, it occupies a vast area in the North American states; and, by recent accounts, has been detected in the western river-plains of South America.

236. *The physical aspect of chalk districts* is easily distinguished by the smooth flowing outline of the hills and valleys. Here there are no rugged and lofty peaks, as in the earlier formations; no tabular-looking escarpments, as in the lias and oolite; but easy undulations, forming in their extent the well-known "wolds" or "downs" of southern England. These downs are characterised "as covered with a sweet short herbage, forming excellent sheep pasture, generally bare of trees, and singularly dry even in the valleys, which for miles wind and receive complicated branches, all descending in a regular slope, yet are frequently left entirely dry; and, what is more

singular, contain no channel, and but little other circumstantial proof of the action of water, by which they were certainly excavated." Chalk districts thus possess great amenity and rural beauty, and are as yet but little broken up by the enterprise of modern agriculture.

237. *The minerals of commerce* derived from the system are by no means numerous. Chalk is used for many purposes in the arts and in agriculture; it furnishes polishing paste, and the well-known whitening of the painter. Beds of fuller's earth occur in the lower green-sand, and in some districts the more indurated strata of the group produce a rough building-stone. Flint is one of the most valuable products of the system; furnishing material for the manufacture of china and porcelain, flint-glass, and gun-flints—the latter having been in universal use before the invention of the percussion cap.

238. *The formation of flint*, within a mass so different in composition as chalk, is still in some respects an unsolved problem in geology. It occurs in nodular masses of very irregular forms and variable magnitude; some of these not exceeding an inch, others more than a yard in circumference. Although thickly distributed in horizontal layers, they are never in contact with each other, each nodule being completely enveloped by the chalk. Externally, they are composed of a white cherty crust; internally, they are of gray or black silex, and often contain cavities lined with calcedony and crystallised quartz. When taken from the quarry they are brittle and full of moisture, but soon dry, and assume their well-known hard and refractory qualities. Flints, almost without exception, enclose remains of sponges, alcyonia, echinida, and other marine organisms, the structures of which are often preserved in the most delicate and beautiful manner. In some specimens the organism has undergone decomposition, and the space it occupied either left hollow, or partially filled with some sparry incrustation. From these facts, it would seem that flints are as much an aggregation of silex around some organised nucleus, as septaria (par. 192) are aggregations of clay and carbonate of iron. This is now the generally received opinion; and when it is remembered that the organisms must have been deposited when the chalk was in a pulpy state, there can be little difficulty in conceiving how the silex dissolved through the mass would, by chemical affinity, attach itself to the decaying organism. Chalk is composed of carbonate of lime, with traces of clay, silex, and oxide of iron; flint, on the other hand, consists of 98 per cent. of pure silex, with a trace of alumine, oxide of iron, and lime. Silex is quite capable of solution: it occurs in the hot-springs of Ice-

land and most thermal waters ; has been found in a pulpy state within basalt ; forms the *tabasheer* found in the cavities of the bamboo, and the thin pellicle or outer covering of canes, reeds, grasses, &c. ; and siliceous concretions are common in the fruits and trees of the tropics. All these facts point to a very general diffusion of silex in a state of solution ; and whatever may have caused its abundance in the waters during the deposition of the upper chalk, there can be little doubt respecting the mode in which it has been collected around the organic remains of these early seas.

EXPLANATORY NOTE.

THE ORIGIN OF CHALK, so different in its texture and appearance from all other limestones, has given rise to many hypotheses. "There appears no evidence," says Mr Brande, "of its having been deposited from chemical solution ; but, on the other hand, it bears marks of a mechanical deposit, as if from water loaded with it in fine division. And upon this principle, some gleam of light may perhaps be thrown upon the enigmatical appearance of the flints ; for it is found, that if finely-powdered silica be mixed with other earthy bodies, and the whole diffused through water, the grains of silica have, under certain circumstances, a tendency to aggregate into small nodules ; and in chalk, some grains of quartz are discoverable." There can be little doubt that such has been the original state of chalk, from whatever source derived ; for, without the supposition that the calcareous particles were diffused through the waters in which it was deposited, it were impossible to account for almost any of the phenomena connected with it as a formation. But while such has evidently been the origin of the great mass of the chalk rocks, it does not preclude the chemical agency of springs, or the organic efforts of secreting animalcules. All other limestones in the crust of the earth point to a complex formation, in which mechanical, chemical, and organic agencies have been concerned ; and it is but reasonable to suppose that chalk is the result of similar forces.

BELEMNITES (Gr., *belemnion*, a dart)—a genus of fossil-chambered shells, perforated by a siphuncle, and so called from their straight dart-like form. Unlike other chambered shells, they were *internal* ; that is, enclosed within the animal like the *pen* of the squid and cuttle-fish. Many of these belemnites are of great size, showing the gigantic nature of the cephalopods to which they belonged. Being long, straight, and conical, they are commonly known by the vernacular names of "thunder stones" and "thunder bolts."

TERTIARY STRATA.

239. THE TERTIARY SYSTEM comprises all the *regular strata* of limestone, marl, clay, sand, and gravel which occur above the chalk. Before the labours of the celebrated Cuvier and M. Brogniart, these beds were regarded as mere superficial accumulations, not referrible to any definite period. Now, however, they are recognised as constituting a distinct formation—differing from the cretaceous not only in its mineral composition, but in the higher order of organisms which it contains, and from the superficial sands and clays, in being regularly stratified, and in imbedding the remains of animals distinct from existing races. In general the strata are loosely aggregated, are of no great thickness, and present appearances which indicate frequent alternations of marine and fresh-water agencies. Thus, marine remains are found in some beds, while others contain exclusively land animals and plants, and fresh-water shells. The whole suit being less consolidated than any of the secondary systems, and containing plants and animals approaching to existing forms, it presents a freshness of aspect which serves to distinguish it from older deposits; at the same time the regularity of its deposition prevents it from being mistaken for any mere alluvial accumulation. In general it occupies very limited and detached areas, as if it had been formed in shallow inland seas and estuaries, to which the waters of the ocean at times had access, and where at other periods fresh-water inundations prevailed. Another essential difference between the tertiary and the more ancient formations consists in the fact, that the latter maintain a wonderful uniformity in their composition and character all over the globe; whereas the former present almost as many distinctions in composition as there are areas of deposit. For this reason it is impossible to give a description applicable to all tertiary strata; those of England and France, however, may be taken as types sufficiently characteristic.

240. *Respecting the composition of the system*, arenaceous and argillaceous beds may be said to prevail, with interstratified limestones, calcareous grits, and marls. The *arenaceous* members are either pebbly conglomerates of a rusty yellow, or sands little indurated and variously tinted by the oxide and silicate of iron. The sands are seldom sufficiently consolidated to form sandstones; and the conglomerates are often mere layers of rolled pebbles, without any cementing matrix. The *argillaceous* beds also present many varieties; some being

almost pure laminated clay of a dull blue colour, others of a brownish tint, with a slight admixture of sand, while many pass into marls more or less calcareous. None of these clays are so compact as to form shales; indeed lamination is more frequently absent than otherwise, there being nothing except their fossils and associated beds to distinguish them from the clays of subsequent alluvial valleys. The *calcareous* layers are still more varied in their composition and aspect, and bear no resemblance to the indurated half-crystalline limestones of older formations. The marine limestone of the Paris basin is of a coarse sandy texture; that of Austria a rough coralline rock: the fresh-water beds near Weimar are hard and compact; those of other districts are soft, marly, and full of shells. In some localities marls are so calcareous as to be used as limestones, while in others they pass into soft friable clays. From this extreme diversity of composition, it is evident that many agencies have been concerned in the deposition of the tertiary system, and that most of them have been of a local character, producing results not differing widely from those of the present day.

241. *The succession of strata* is no less varied than their mineral composition. As at the present day distant rivers are depositing different sorts of material at one and the same time, so in distant tertiary basins different strata variously succeed each other. Luckily, none of the deposits are of great thickness, and as they have been closely examined for the sake of their fossils, the alternations of the beds have been pretty accurately ascertained. The following is a descending section of the Paris basin, according to Cuvier and Brogniart:—

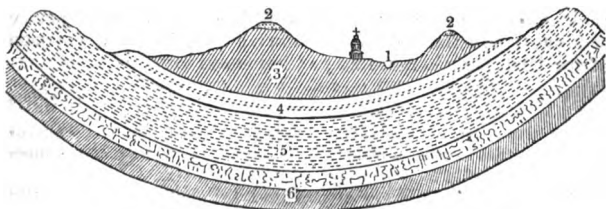
5. UPPER FRESH-WATER GROUP—marls, marly sands, shelly limestone, and siliceous or *burr* limestone.
4. UPPER MARINE GROUP—marls, sands and sandstones of a white or ochraceous colour, and loosely aggregated; thin layers of limestone.
3. LOWER FRESH-WATER—marls, gypsum (sulphate of lime), with bones of animals, and siliceous limestones.
2. LOWER MARINE—consisting principally of a coarse sandy limestone (*calcaire grossier*), with calcareous marls and layers of greenish sand.
1. PLASTIC CLAY GROUP—consisting of bluish plastic clays, with layers of sand, beds of lignite, and rolled pebbles. Supposed to be of estuary origin.

Although a very different succession takes place among the tertiaries of the south of England, yet there is sufficient resemblance in the position and aggregation of their strata, as well as in their organic remains, to establish the fact, that they belong to the same epoch as the rocks of the Paris basin. The

annexed section shows the order of their occurrence to the south of London :—

4. BAGSHOT SANDS.
3. LONDON CLAY—of a dull gray, or blue, or ochraceous colour ; often full of green grains. Septaria and other ferruginous nodules occur in some parts. Numerous fossils.
2. PLASTIC CLAY AND SANDS—sands of various colours, with occasional beds of lignite ; also layers of sandy clay, with or without shells.
1. SANDS—green and ferruginous, accompanied by flint pebbles, oyster shells, &c.

In other parts of England the order of occurrence is somewhat different. It may be stated, however, in general terms, that the sands are most extensively developed ; the clays chiefly in the southern basins ; while at Oxford, Ramsholt, &c. the upper beds consist of a coarse conglomerate of corals, sand, pebbles, shells, &c. locally known as the “Crag,” and so calcareous in some places as to be used as a limestone. As with the Paris and English deposits, so with other tertiary basins in Europe ; those of southern France, Spain, Italy, Austria, Hungary, &c. —all showing an irregular succession of clays, sands, marls, lignites, and gypsum, which, when examined in relation to their positions, modes of aggregation, and fossils, are clearly referrible to the same period of formation. The following engraving illustrates the tertiary deposits of the Thames basin, with the subjacent chalk and green-sand :—



1. River Thames ; 2. Marine sands ; 3. London clay ; 4. Plastic clay and sands ;
5. Chalk with flints ; 6. Green-sand and Gault-clay.

242. *As to the extent of country occupied by tertiary deposits,* there is yet no very accurate knowledge, inasmuch as many sands and clays, now regarded as the alluvium of existing valleys, may hereafter be referred to this system ; and several areas of gravel, now looked upon as tertiary, be classed with more recent accumulations. As developed in Europe, the system spreads over wide areas, all remarkable for their conformation and connexion with the outline of existing seas.

Indeed, were the islands and continent of Europe to be submerged to the depth of 600 or 800 feet, the waters of the German, Baltic, English Channel, and Mediterranean seas, would cover most of the tertiary strata, showing that, with the exception of the general elevation which raised them into dry land, there has been comparatively little subterranean disturbance since the time they were deposited. In Britain the formation is exhibited in Hampshire, Isle of Wight, in the basin of London, and from the Thames northwards along the coast to the mouth of the Yare; but has not been detected either in Ireland or Scotland, though several gravel and clay deposits in the latter country may yet be discovered to belong to the same era. It occurs interestingly developed near Paris; trends along the north coast of France, Belgium, Westphalia, Holstein, and Jutland, in apparent connexion with the German Ocean; spreads over the level tract lying between the Baltic and Northern Ocean in Russia; and occupies the greater portion of the central flats which lie between the Baltic and Black seas. Besides these expanses, there are many secluded patches along the valleys of the Rhone and Danube, the Swiss lakes, and the Italian shores of the Mediterranean. The system has also been detected along the southern basis of the Himmalehs, and in several of the North American valleys; and when geological research has been farther extended, there is little doubt of its being discovered in other quarters of the world. In speaking of the extent of country occupied by deposits of incoherent sands, marls, and clays, like those of the tertiary epoch, it must be borne in mind how much more waste they would suffer by denudation than the older and more consolidated strata. No doubt every rock system, on its being elevated into dry land, must have suffered diminution by denuding causes; but most of all those whose materials are loosely aggregated like the strata now under review.

243. *Igneous rocks* are not found in connexion with the tertiaries of England, though subterranean movements have thrown them into anticlinal ridges and basin-shaped hollows. In the south of Europe the case is otherwise, and the geologist finds in the igneous discharges of Auvergne, Switzerland, the Rhine, Hungary, and Italy, a link which connects the traps of the secondary period with the products of recent and active volcanoes. According to M. de Beaumont the western Alps (from the Mediterranean to Mont Blanc) were upheaved during this era; and the eastern range is supposed to be of still more recent origin, or at all events not to have been upraised till after the deposition of all the tertiary

strata. Along the Rhine, in Hungary, and in central France, the igneous elevations assume a more diminutive aspect—those of Auvergne never arranging themselves in a continuous axis, but presenting a congeries of conical crateriform hills of no great altitude. In their composition, these igneous rocks are chiefly trachytic—passing from a pretty compact grayish felspathic mass to scoriaceous tufa; but in no case presenting the dark bituminous aspect of the coal-measure traps, nor the amygdaloidal and porphyritic texture of those associated with the old red sandstone.

244. *Respecting the geographical aspect* of tertiary districts, the general absence of igneous rocks would indicate a level and somewhat unvaried scenery; and this is the feature which prevails in the wide tertiary plains of northern and middle Europe. In England the strata partake of the undulations of the subjacent chalk, principally developed, however, in the flatish basins of London and Hampshire. From the open and porous character of the sands and gravels, tertiary soils are in general light and dry, capable of profitable cultivation, but by no means naturally fertile. The hills and vine-growing slopes of Auvergne can scarcely be considered as reposing on a tertiary basis any more than the snow-clad crags and peaks of the Alpine range, both of which form decided exceptions to the general rule.

245. *The organic remains of the system* constitute its most important and interesting feature. The fossils of earlier periods presented little analogy, often no resemblance, to existing plants and animals; here, however, the similitude is frequently so complete, that the naturalist can scarcely point out a distinction between them and living races. Geology thus unfolds a beautiful gradation of being from the corals, molluscs, and simple crustacea of the grauwacke—the enamelled fishes, crinoidea, and cryptogamic plants of the lower secondary—the chambered shells, sauroid reptiles, and marsupial mammalia of the upper secondary—up to the true dicotyledonous trees, birds, and gigantic quadrupeds of the tertiary epoch. The student must not, however, suppose that the fossils of this era bring him up to the present point of organic nature, for thousands of species which then lived and flourished became in their turn extinct, and were succeeded by others long before man was placed on the earth as the head of animated existence. Of *Plants*, few marine species have been detected; but the fresh-water beds have yielded cycadeæ, coniferæ, palms, willows, elms, and other species, exhibiting the true dicotyledonous structure. Nuts allied to those of the cocoa and other palms have been discovered in the London

clay; and seeds of the fresh-water *characeæ*, or stoneworts, known by the name of *gyrtonites* (Gr., *gyros*, curved, and *gonos*, seed), are common in the same deposit. Of the *Radiata*, *Articulata*, and *Mollusca*, so many belong to existing genera, that the circumstance has suggested a classification of tertiary rocks according to the number of recent species which they contain. Thus, if out of 100 fossil shells 80 should belong to recent species, the deposit in which they are imbedded is presumed to be of later origin than one from which only 10 per cent. of recent shells can be obtained. Proceeding upon this plan, M. Deshayes and Mr Lyell arrange the entire system into the following groups, as further explained in note, page 72 :—

PLEISTOCENE—Sicilian deposits, with 95 per cent. of recent species.

PLEIOCENE—Italian and Crag deposits, with 41 per cent. of recent species.

MEIOCENE—Vienna, Bordeaux, Turin, &c. 18 per cent. of recent species.

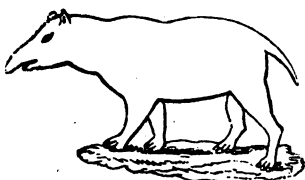
Eocene—Paris, London, Belgium, 3½ per cent. of recent species.

From the above per centage the student will perceive, with respect to the marine mollusca of the tertiary era, that they approach existing forms too nearly to require any particular description.

246. *The vertebrate animals* make a similar approach to, or recession from, existing races as we ascend or descend among the tertiary strata. “*The Fishes*,” says M. Agassiz, “are so nearly related to existing forms, that it is often difficult, considering the enormous number (above 8000) of living species, and the imperfect state of preservation of the fossils, to determine exactly their specific relations. In general, I may say that I have not yet found a single species which was perfectly identical with any marine existing fish, except the little species which is found in nodules of clay, of unknown geological age, in Greenland. The species of the Norfolk crag, of the upper subapennine formation, and of the molasse, are mostly referrible to genera common in tropical regions. In the lower tertiaries of London, the basin of Paris, and Monte Bolca, at least a third of the species belong to genera which are now extinct.” As with the fishes, so with the *Reptilia*, among which we find, for the first time in the history of the globe, the remains of genuine crocodiles, snakes, and representatives of the frog tribe; besides several existing genera of fresh-water and marine turtles. The saurians of the saliferous and oolitic eras had by this time passed away, to be succeeded by the above-named reptiles, whose forms and habits seem to have been more in accordance with the altered conditions of external nature. Of *Birds*, eight or ten species have been discovered

in the Paris basin, referrible to the genera—buzzard, owl, quail, woodcock, sea-lark, curlew, and pelican.

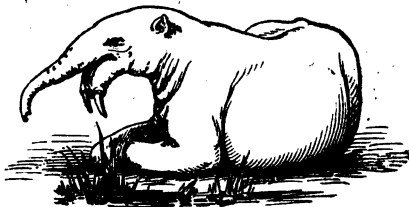
247. *The mammalia of the tertiary strata* are those fossils which have most attracted the attention of palæontologists; and this deservedly so, from their being the prototypes of many existing species, and as marking the dawn of conditions suited to the Fauna of the present day. Of these ancient forms, between fifty and sixty species have been determined, a majority of which belong to a division of the order *Pachydermata*, now only represented by four living species; namely, three tapirs, and the daman of the Cape. This division comprehends most of the *theroid* animals, now so frequently alluded to in works on geology, of which the *palæotherium* (see fig.) was one of the most prevalent and characteristic. A detailed enumeration of the mammalia of this era would be



Form of *Palæotherium*.

inconsistent with the rudimentary nature of this treatise; we shall therefore merely advert to the leading orders now determined by the most eminent fossil anatomists. *Quadrumana* (four-handed, or monkey tribe), one or two species from the eocene beds of the English basins; *Marsupialia* (pouch-nursing), three or four species of a diminutive size; *Cheiroptera* (hand-winged), two or three species of bat, chiefly from the gypsum beds of Montmartre; *Insectivora* (insect-eaters), partial remains of a species of mole; *Carnivora* (flesh-devourers), several species have been determined allied to the bear, hyæna, fox, dog, seal, cat, weasel, &c.; *Rodentia* (gnawers), ten or twelve species allied to the beaver, rat, hare,

lagomys, squirrel, &c.; *Pachydermata* (thick-skinned), many genera and species, such as the mastodon, the deinotherium



Restored Form of *Deinotherium*.

lagomys, squirrel, &c.; *Pachydermata* (thick-skinned), many genera and species, such as the mastodon, the deinotherium

(see fig.), elephant, hippopotamus, rhinoceros, horse, boar, tapir, and a host of animals allied to the tapir; *Ruminantia* (cud-chewers), a few species, as the stag, deer, elk, antelope, ox (?), &c.; *Cetacea* (whales), one or two species; and gigantic *Edentata* (toothless animals), now faintly represented by the sloth, the ant-eater, and the diminutive armadillo.

248. *Of the conditions of the world during the deposition of the tertiary strata*, we are enabled to form some estimate from the nature of their fossils, and from the peculiar composition and aggregation of their rocky materials. So far as Europe is concerned, part of the existing land must have been then elevated above the waters, forming a series of insular ranges, with flat valleys and shallow seas between. From these islands, and from continents now submerged, rivers of considerable extent seem to have borne sand, clay, and vegetable debris, and to have deposited them in the seas and estuaries, while gravel, flint pebbles, broken corals, and shells, were strewn along the shore by ordinary littoral influences. Such materials would give rise to beds of sand, clay, gravel, lignite, and calcareous conglomerate, enclosing marine remains, with others of fresh-water and terrestrial origin brought down by the rivers. But several tertiary basins exhibit strata of decided fresh-water origin, alternating with others as decidedly marine; and to account for this phenomenon, we must have recourse to another set of agents. In the deltas of many modern rivers, like that of the Niger, lagoons of fresh-water are frequently cut off from connexion either with the branches of the river or with the ocean, and in these myriads of shell-fish, aquatic plants, crocodiles, hippopotami, and other fresh-water and amphibious races abound. At some subsequent period the connexion with the ocean is renewed—there being in general only a slight eminence of mud or sand to separate them—and thus the succeeding deposits assume a character decidedly marine. By these means it is easy to conceive how alternations of marine and fresh-water strata would occur; and particularly when we know that the south of Europe (central France and the Alps) was, during the tertiary era, subjected to extensive volcanic disturbances, which would give rise to frequent submergences and elevations. We are thus enabled to account for the composition and aggregation of the tertiary strata; and when we reflect on their comparatively recent origin, and the fact that they are in many places not overlaid by other material, there is no difficulty in perceiving how they should be so loose and incoherent in their texture. Again, when we look at the nature of their fossils, we are led to associate with them ideas of a warm and genial climate. The lands which furnished

the cycadeæ, palms, cocoa nuts, and monkeys of the English tertiary, and the mastodons, elephants, rhinoceroses, hippopotami, crocodiles, and turtles of the Paris basin, must have enjoyed a temperature similar to that of the present tropics. The beds of lignite bear evidence of a luxuriant vegetation for the support of so many huge graminivora; while the presence of birds, insects, and the higher orders of mammalia, point to atmospheric and other vital conditions little different from those now existing. In fact, we find in the deltas of the Ganges and Niger—in their jungles, lagoons, and swamps—in their elephants, hippopotami, and crocodiles—almost perfect analogies to those estuaries and shallow seas in which the tertiary strata of Europe were deposited.

249. *In an economical point of view*, the tertiary strata are of considerable local importance. The celebrated *burr* millstones of France are obtained from the upper fresh-water siliceous limestones of the Paris basin; some of the strata of which also furnish marble capable of receiving a high polish. Marked by the numerous shells which are imbedded in it, this marble is by no means unornamental, and has been used in the construction of the *jets d'eau* in the galleries of the Tuilleries. Many of the fresh-water limestones rapidly disintegrate on exposure to air and moisture, and, falling down to the state of marl, are used as manure; while the “crag” is occasionally so calcareous, as to serve the ordinary purposes of limestone. Pipe and potters’ clay are extensively obtained both from the London and Paris basins; the term *plastic*, applied to the lower beds, being derived from the circumstance of the clay readily receiving the mould or form of the potter (Gr., *plasso*, I form). Gypsum (sulphate of lime) is perhaps the most valuable member of the deposit; it is found abundantly in the Paris basin, and when calcined, reduced to powder, and kneaded with water, forms the well known *plaster of Paris* so extensively used by image-makers, plasterers, stereotype-founders, and others. Gypsum has also been recently applied as a top-dressing to crops, and as a fixer of the volatile principles of organic manures. Lignite (Lat., *lignum*, wood), or wood-coal, is found in some tertiary districts, the only deposit of importance in England being that of Bovey Hayfield, near Exeter. Amber frequently occurs with these lignitic beds, and appears to have been a gum or gum-resin exuded by the trees with which it is associated.

EXPLANATORY NOTE.

THEROID ANIMALS.—The termination *therium* (Gr. *therion*, a wild beast) is adopted in geology to designate certain classes of fossil

mammalia whose structure and habits have not yet been fully established by anatomists. The individual animals are characterised by a prefix which applies to some peculiarity of form, the place where found, or the name of the discoverer. Thus we have the *deinotherium* (terrible wild beast); the *palæotherium* (ancient); the *anoplotherium* (unarmed, having no weapons of defence); the *megatherium* (great); the *elasmotherium* (from the laminated structure of its teeth); the *anthracotherium* (found in the lignitic beds); the *cainotherium* (recent); the *sivatherium* (found in the Sivalic range of the Himmalehs); &c. Though most of these animals are found in tertiary deposits, it would appear that some, such as the megatherium, outlived that era, and continued inhabitants of the globe long after the commencement of the current epoch.

SUPERFICIAL ACCUMULATIONS.

250. *After the deposition of the Tertiary Strata*, a great change took place in the relative distribution of land and ocean. Most parts of Europe, America, and the other continents were elevated above the waters; other regions seem to have been submerged, and an arrangement of physical conditions established not differing widely from those now existing. But these new conditions did not for an instant arrest the degrading and transporting power of water, the wasting effects of the atmosphere, the disturbing efforts of volcanoes, or the progressive development of organic life: the same agents which had exerted themselves, from the beginning of time, in modifying the physical features of the world, continued their career, only differing in power and degree according to this new arrangement. Thus, accumulations of sand, gravel, clay, vegetable and animal matter took place above the previously deposited strata—every river, lake, sea-shore, shell-bed, coral-reef, and peat-moss, contributing its peculiar quota. It is to such recent and progressive formations, now occupying the surface of the earth's crust, that the attention of the student is here directed.

251. The term "*Superficial Accumulations*" is applied to these loosely-aggregated masses of matter—whatever be their composition or mode of formation—to distinguish them from the tertiary sands and clays, in all of which *stratification* is distinct and undeniable. Other designations have been proposed, such as *post-tertiary* (after-tertiary), *quaternary* (fourth system), &c.; but that which we have chosen merely indicates their position, leaving further subdivisions to be made in the course of description. The most natural division is that which attempts to arrange these accumulations according to the respective dates of their formation. Thus:—

1. Deposits now in progress, and depending upon ordinary causes.
2. Those whose origin depended upon ordinary causes now dormant.
3. Those which owe their origin to extraordinary causes now dormant.

A classification of this kind, however, is attended with so many difficulties, that it is next to impossible to adopt it with any degree of accuracy. For instance, it is often very difficult to distinguish the gravel of some ancient lake, containing bones of the stag, elk, and elephant, from true tertiary strata; and who shall decide whether certain inland ranges of sand and gravel arose from extraordinary or ordinary causes? Again, in many valleys alluvial matter has been accumulating from the time that they received their existing configuration up to the present day, thus making the most ancient and most recent of such deposits depend upon one long-continued and progressive agency. Further, an iceberg laden with rock debris and boulders, strewing its burden, as it melts away, along the bed of the ocean, is an ordinary operation; yet were the bottom of the sea, with its mud, gravel, and immense boulders, to be elevated into dry land, appearances would present themselves which geologists would be very apt to ascribe to violent and unusual operations of water. Under these circumstances, the more philosophical mode of treating the Superficial Accumulations will be to adopt no classification which involves either the time, the ordinary or extraordinary cause of their formation; but simply to treat them in succession according to their composition, or the agents obviously employed in their deposition. Following out this view, the principal agencies and their results may be arranged as under:—

<i>Agencies.</i>	<i>Nature of Accumulations.</i>
DETRITAL.	<ul style="list-style-type: none"> { Erratic blocks or boulders; dark tenacious clays. { Ossiferous gravels, sands, and pebbly clays. { Ossiferous caves, fissures, and breccia.
MARINE.	<ul style="list-style-type: none"> { Raised or ancient beaches; submarine forests. { Marine silt, sand-drift, shingle beaches, &c. { Submarine deposits and accumulations.
FLUVIATILE.	<ul style="list-style-type: none"> { Terraces on valley sides, marking successive water-levels. { Valley deposits, consisting of river sand, gravel, silt, &c. { Deltoid or estuary deposits, ancient and progressive.
LACUSTRINE.	<ul style="list-style-type: none"> { Sites of ancient lakes now silted up with various debris. { Marls, such as shell, clay, and calcareous marls. { Lacustrine silt, and accumulations now in progress.
MINERAL AND CHEMICAL.	<ul style="list-style-type: none"> { Calcareous—calo-tuff, sinter, travertine, stalactites, and stalagmites. { Siliceous and aluminous deposits from springs, &c. { Saline and sulphurous deposits from springs, from the sea, volcanoes, &c. { Bituminous exudations, pitch lakes, &c.

ORGANIC.	{	Vegetable—peat-mosses, jungles, vegetable drift.
		Animal—shell-beds, coral-reefs, &c.
		Soils—primitive earths, with admixtures of organized matter.
VOLCANIC.	{	Earthquakes—elevations and depressions, &c. caused by
		Volcanoes—elevations, disruptions, and other changes caused by
		Discharges and accumulations of lava, scorix, dust, &c.

The above synopsis comprises all masses of matter which produce any sensible modification of the earth's surface; other accumulations than these must be of a very local and limited description.

ERRATIC BLOCK, OR BOULDER, GROUP.

252. The terms "*erratic block group*," "*boulder formation*," "*diluvium*," and "*diluvial drift*," are indiscriminately given by geologists to a thick mass of dark tenacious clay which overlies extensive districts, intermingled with numerous boulders having a rounded and water-worn appearance. There is nothing like regularity of deposit in this formation, unless it may be said that it attains the greatest thickness and uniformity of composition on extensive plateaus like those of the coal measures, at the eastern extremity of certain valleys, and on the south-eastern flank of hills belonging to the secondary period. The clay is generally of a dark blue colour, though in some localities it assumes a reddish hue. There are no lines of lamination in the mass, and no appearances of stratification, unless in some districts where there is a sort of natural division into "upper and lower clays"—the lower being dark and more compact, the upper lighter in the hue, and separated from the other by a thin reddish streak. Waiving these minutix, the whole may be described as a covering of compact dark clay, from 10 to 120 feet in thickness, full of boulders and rolled stones from the size of an egg to many tons in weight; these blocks occupying the bottom, middle, or surface of the mass, without regard to gravity or any other law of arrangement. The boulders are of granite, syenite, primitive greenstone, gneiss, mica schist, and other crystalline rocks of a hard and durable texture. Limestone blocks are of very rare occurrence, and the more friable rocks of the upper formations are seldom or ever to be met with. This clay, with its intermingled boulders, generally rests upon the denuded outcrops or edges of the rock formations; is sometimes underlaid by masses of gravel; and not unfrequently contains "nests," or irregular patches of rounded pebbles.

253. *Besides these patches which are interwoven with the clay,* there are independent accumulations of gravel, and rubbly masses of rock-fragments, which seem to have been formed contemporaneously with the boulder-clay, and by the same agency. In Britain such accumulations generally occupy the eastern extremity of longitudinal valleys, where they form curious ranges of flat-topped hillocks; abut against the base of some mountain; or gather, without regard to any order of arrangement, along the eastern flank of those trap hills which present a bold front or "crag" to the westward. They are found for the most part in more open situations than the clay, as if they had been arrested in their progress eastward by prominences and shallows, while the clays were borne to deeper and more sheltered recesses. Like the dark clays, they are destitute of organic remains, their larger pebbles are derived from primitive rocks, interspersed with fragments of sandstone, shale, and coal from the secondary formations.

254. *To account for the origin of the group thus described,* many theories have from time to time been advanced, of which only two deserve notice, as being at all adequate to the purpose intended. The *first* is that which supposes a set of powerful currents to have passed over Britain and the adjoining continent; these currents taking a course from the north and north-west towards the south and south-east, and sweeping before them clay, sand, gravel, and loose blocks, which were deposited, as the force of the waters abated, without any order or arrangement. How long the currents continued, theorists do not aver; but from the water-worn aspect of the boulders and gravel, an indefinite period is allowed. With respect to the direction of the drifting force, little doubt is entertained, for many reasons:—1. Blocks of granite, gneiss, &c. which must have been derived from the Grampians, are found scattered along the eastern lowlands of Scotland; primitive rocks from the Lammermuir and Cheviot ranges are detected in the vale of the Tweed and in Northumberland; others from the Cumberland mountains are widely dispersed over Durham and the east of Yorkshire; boulders from the Welsh range are found in the midland counties of England; while the erratic blocks of Friesland and Germany point to the Scandinavian ridge as the source from which they were derived. 2. Those hills which range east and west have, without exception, their western brows swept bare, while their eastern flanks are thickly strewed with gravel and boulders. 3. Many accumulations of gravel bear evidence of their having been piled up by a force from the north-west. 4. Blocks evidently derived from the outcrops of certain strata are often

found among the debris a few yards to the south-east, showing clearly that the transporting power passed over them from the north-west. 5. The supposed currents have been modified in their direction by ranges of hills, so as to set the volume of water with greater rapidity down the valleys which lie between them, as the greatest accumulations of drift and boulders are found at the eastern extremities of such gorges and valleys. But while no doubt is entertained either as to the agency of water in the formation of these accumulations, or as to the direction in which the waters flowed, great difficulty is felt in conceiving any current sufficiently powerful to sweep before it blocks of several tons weight, and that over heights and hollows for many hundreds of miles. Indeed it seems impossible to reconcile the theory of violent currents with the phenomena presented; for, granting the occurrence of some extraordinary cataclysm, during which the waters of the ocean were thrown over the land, the currents must have abated in velocity as they drew to a close, leaving the detritus to arrange itself more in accordance with the laws of gravity than what is exhibited in a mass of clay and boulders.

255. *The second theory* supposes that those portions of Europe now covered with erratic blocks were submerged after the deposition of the stratified formations; that this submergence was caused by some extraordinary revolution in the planetary relations of our earth; that it was accompanied by a change of climate, and other terrestrial conditions; that while in this state, icebergs and avalanches formed around the earlier mountains which were still left above water; and that these icebergs, as they were loosened from the shore by the heat of summer, and floated southward by the currents of the ocean, dropped their burden of boulders and gravel precisely as Captain Scoresby (page 24) found modern icebergs dropping their debris in the northern seas, and as the officers of the recent Antarctic expedition observed similar phenomena in the Southern Polar Ocean. It is further supposed, that while icebergs distributed the erratic blocks and other debris in deep waters, avalanches and glaciers were forming *moraines* of gravel in the valleys of the then existing land analogous to what is observed in the alpine glens of Switzerland. Again, one cannot read Mr Simpson's account of the shores of the Polar seas, and learn that the ice formed during winter over whole leagues of gravel, breaks up during summer, and is blown on the beach by winds, or piled up by the tides, where, melting, it leaves long flat-topped ridges, without perceiving a wonderful resemblance between these effects and the long singularly-shaped ridges of "diluvial" gravel. According

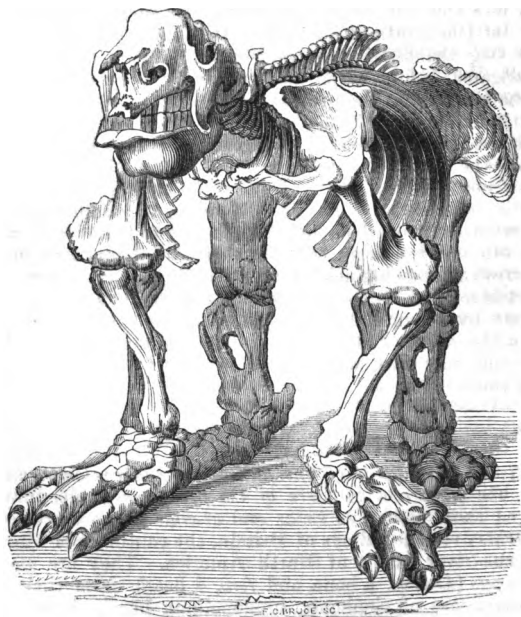
to this theory, it is easy to account for the south-eastward direction of the drift, for the Polar Ocean still maintains its great southward current to the equatorial seas, modified, undoubtedly, in its course, by the inequalities of the bottom over which it passes. The chief difficulty to be obviated is the temporary diminution of temperature which the north of Europe must have then experienced; and this can only be accounted for by some derangement in the planetary relations of our globe.

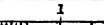
256. *Both theories are beset with many difficulties*, and though the latter accounts more satisfactorily for most of the phenomena of the erratic block group, still there are many points respecting the distribution and extent of the deposit to be investigated before either can be finally adopted. All that can be affirmed in the present state of the science is the composition and nature of the clay, gravel, and boulders, as above-described—the course of the currents concerned in their deposition—the fact of the land having a configuration of hill and valley not differing much from what now exists—and the peculiar scantiness, if not total absence, of organic remains. If the latter theory be adopted, it is easy to perceive how the soft bottom of the ocean, as it was elevated into dry land, would be furrowed and channeled by the receding waters—here being swept bare of its mud, but retaining the boulders; there being covered by accumulations of transportable clay and gravel; while the deeper hollows being left undrained, would form lakes and morasses, which were in turn to be silted up by subsequent material.

OSSIFEROUS SANDS AND GRAVEL.

257. *Next in point of antiquity to, if not contemporaneous with, the clays and boulders of the preceding group*, may be ranked those ossiferous sands and gravels found scattered at intervals over the valleys of Britain, the continent of Europe, and the river plains of North America. They are termed *ossiferous* (Lat. *os*, a bone, and *fero*, I bear), from their containing bones of elephants, hippopotami, horses, bears, deer, and other animals, which belong to existing species, but do not now inhabit the regions where these remains occur. For instance, large portions of England, Wales, Scotland, and Ireland are covered by irregular accumulations of rounded pebbles and gravelly sands, in which are found bones of the elephant, hippopotamus, &c. none of which have been known in this country within the historic period. In similar deposits the skeletons of elephants and mammoths have been discovered in

Siberia and the north of Europe ; the bones of the mammoth, mastodon, and megatherium in America ; and even among the Esquimaux of the Polar seas Captain Ross and Mr Simpson observed platters fashioned from the fossil grinders of these gigantic mammalia. Neither at present, nor throughout the whole historic period of four thousand years, have any of those countries been in conditions of climate to support such huge graminivora, and therefore geologists are compelled to assign a very remote and ancient origin to the gravels in which their relics are entombed.



Scale of  Feet.

Skeleton of Megatherium.

258. *The composition and aggregation of these sands and gravels point to the long-continued action of water by which their pebbles were rounded and smoothed like those of the rivers, lakes, and sea-shores of the present day. The mineral*

character of the pebbles enables the geologist often to decide with certainty as to the quarter from whence they were drifted ; and in Britain this generally corresponds with that from which the erratic blocks were derived. Like the boulders, the great mass of the pebbles are from primitive rocks, interspersed with secondary sands, rolled flints, and calcareous cement. The imbedded bones are more or less impregnated with iron and lime, are harder and heavier than recent bone, but never so much petrified as to obliterate the bony structure. The gravels have all a light ferruginous tint, and can only be distinguished in certain localities from true tertiary gravel by the recentness of their fossils, or by some circumstance of position or mode of aggregation.

259. *Much uncertainty prevails with respect to the origin and aggregation of these ossiferous sands and gravels.* Many of them are no doubt local, and have been formed by the action of rivers, the silting up of lakes and other extensive shallows ; and could such be separated from those which appear to have been accumulated by some very powerful and extensive agency, the task were greatly simplified. Unluckily, however, this seems to remain an insuperable difficulty, so that geologists are compelled to class together all deposits of ancient ossiferous gravel into one group, without much regard to the agencies concerned in their accumulation. This grouping is rendered still more indefinite by the assertion of some eminent geologists, that ossiferous gravels have been found underneath the erratic boulder clay, containing the same kind of bones with those above it. Should this be the case, it would tend to establish the theory, that the ossiferous gravels and erratic blocks took their origin from the same set of unusual causes ; that they belonged to an era which was posterior to the tertiary, and prior to the existing arrangements of nature ; and that before this epoch, which was of considerable duration, many of the tertiary races had died away, and been succeeded by others, most of which still exist, though now extinct in the regions where they then flourished.

OSSIFEROUS CAVES, FISSURES, AND BRECCIA.

260. *Belonging to the same era with the ossiferous gravels,* and only here separated for the sake of perspicuity, occur numerous caverns and fissures filled with the bones of elephants, rhinoceroses, hyænas, bears, deers, and other animals. These caverns are found in England, France, Belgium, Germany, along the coasts of the Mediterranean, in North America, and in Australia. They are situated almost exclusively in

thick strata of limestone, a rock peculiarly liable to be fissured and worn out by the action of springs and subterranean waters. Among the mud of these ancient caverns, or covered over with calcareous incrustations, lie the bones of land quadrupeds perfectly preserved, and capable of being compared with existing races. "The result," says Professor Phillips, "is extremely remarkable: instead of a large proportion of the existing species of animals, which, during the early periods of history, if not in later times, might have been expected to fall into fissures, retire into caves, or be dragged by wolves to their dens, we find the greater number of bones to belong to elephants, large feline animals, the rhinoceros, hippopotamus, elk, hyæna, indiscriminately entombed with oxen, deer, and many smaller animals." Masses of bones are also found filling fissures and other openings in rocks, mingled with pebbles, mud, fragments of shells, &c. To such accumulations the term *osseous breccia* is applied, from the fragmentary nature of the compound.

261. *The number of ossiferous caverns* is very great, but we can only allude to those which occur in England. In general they are situated on the limestone escarpments of the secondary hills, or on the terraced side of some valley. In the latter case, they are considerably above the existing bed of the valley, though at one time they must have been on a level with the waters which occupied its expanse. The most celebrated are Banwell Cave and Hutton Hole in the Mendip hills, Dream Cavern near Wirksworth, Peak Cavern in Nidderdale, Kents Hole at Torquay, and Kirkdale Cave in Yorkshire. The latter has been thus described:—"Kirkdale Cave is situated about twenty-five miles north-east of York, above the northern edge of the great vale of Pickering, and thirty feet above its waters. Its floor is upon the great scale, level for the whole length yet explored (250 feet), and nearly conformable to the plane of stratification of the coralline oolite in which it occurs. In some parts the cave is three or four feet high, and roofed, as well as floored, by the level beds of this rock; in other parts its height is augmented by open fissures, which communicate through the roof, and allow a man to stand erect. The breadth varies from four to five feet to a mere passage; at the outlet or mouth against the valley was a wide expansion or antechamber, in which a large proportion of the greater bones, ox, rhinoceros, &c. were found. This mouth was choked with stones, bones, and earth, so that the cave was discovered by opening upon its side in a stone quarry. On entering the cave, the roof and sides were found incrustated with stalactites, and a general sheet of stalagmite, rising

irregularly into bosses, lay beneath the feet. This being broken through, yellowish mud was found about a foot in thickness, fine and loamy toward the opening, coarser and more sandy in the interior. In this loam chiefly, at all depths, from the surface down to the rock, in the midst of the stalagmitic upper crust, and, as Dr Buckland expresses it, 'sticking through it like the legs of pigeons through a pie-crust,' lay multitudes of bones of the following animals :—

CARNIVORA—hyæna, tiger, bear, wolf, fox, weasel.

PACHYDERMATA—elephant, rhinoceros, hippopotamus, horse.

RUMINANTIA—ox, three species of stag.

RODENTIA—hare, rabbit, water-rat, mouse.

BIRDS—raven, pigeon, lark, duck, snipe.

The hyæna's bones and teeth were very numerous—probably two or three hundred individuals had left their bodies in this cave; remains of the ox were very abundant; the elephants' teeth were mostly of very young animals; teeth of hippopotamus and rhinoceros were scarce; those of water-rats very abundant. The bones were almost all broken by simple fracture, but in such a manner as to indicate the action of hyænas' teeth, and to resemble the appearance of recent bones broken and gnawed by the living Cape hyæna. They were distributed 'as in a dog-kennel,' having clearly been much disturbed, so that elephants, oxen, deer, water-rats, &c. were indiscriminately mixed; and large bones were found in the narrowest parts of the cavern. The peculiar excrement (*album græcum*) of hyænas was not rare; the teeth of hyænas were found in the jaws of every age, from the milk tooth of the young animal to the old grinders worn to the stump: some of the bones were polished in a peculiar manner, as if by the trampling of animals."

262. *The conclusions to be drawn respecting these ossiferous caverns* are—1. that some of them formed the dens of ravenous animals, like the wolf and hyæna, which dragged in the carcasses of other animals, and feasted upon them in quiet, leaving the bones to be covered in process of time by incrustations of calcareous matter; 2. that others were partially filled by these means, and partly by the drifting in of bones and dead animals by some extraordinary inundation; 3. that many (fissures especially) were filled by the same drifting process, or by the accidental falling in of the animals; 4. that several appear to have been used during successive ages as retreats for animals of all kinds, and even for man himself, as remains of savage life are found in caverns, the floors of which are formed of calcareous incrustations, mud, and the bones of animals extinct long before man made his appearance.

EXPLANATORY NOTE.

BOULDERS, OR BOWLDERS—a term generally applied to rounded masses of stone lying on the surface, or loosely imbedded in the sub-soil. Boulders are found of all sizes, those of granite, syenite, and primitive greenstone being the largest, and often weighing from ten to thirty tons.

DILUVIUM.—The terms diluvium, alluvium, and colluvium, are to be found in all geological works, but the distinctions made between them are often not very obvious. *Colluvium* (Lat., *con*, together, and *lvo*, I wash) is meant to apply to masses of detrital matter washed together, without hinting at the nature of the force by which they were accumulated. *Alluvium* (Lat., *ad*, to) is generally applied to matter brought together by the ordinary operations of water, such as river silt; while *diluvium* (Lat. *dis*, asunder), on the other hand, is regarded as implying the extraordinary action of water. In this sense diluvium was at one time restricted to those accumulations of gravel, &c. supposed to have been the consequence of the Deluge; but it has now a wider signification in geology, being applied to all masses apparently the result of powerful aqueous agency.

MORAINES—the name given in Switzerland to the longitudinal deposits of stony detritus which are found at the bases and along the edges of all the great glaciers. The formation of these accumulations is thus explained by Professor Agassiz:—The glaciers, it is well known, are continually moving downwards, in consequence, probably, of the introduction of water into their fissures, which, in freezing, expands the mass; and the ice being thus loosened or detached from the rocks below, is gradually pressed forward by its own weight. In consequence of this motion, the gravel and fragments of rocks which fall upon the glaciers from the sides of the adjacent mountains are accumulated in longitudinal ridges, or *moraines*.

OSSEOUS BRECCIA.—Any rock composed of an agglutination of angular fragments is designated by the Italian word *breccia*; and when fractured bones are abundantly mingled with the mass, it is termed an *osseous breccia*. A *breccia*, or brecciated rock, differs from conglomerate or puddingstone, in having its component pebbles angular and fragmented, whereas those of the latter are rounded and water-worn.

SUPERFICIAL ACCUMULATIONS—CONTINUED.

RAISED BEACHES—SUBMARINE FORESTS.

263. *Where the sea and land join*, the former, by the action of its waves and currents, soon forms a level beach or shore, along which is strewn sand, gravel, shells, and other marine exuviae. In tidal seas, this beach is successively inundated and exposed by the flowing and ebbing of the waters; and in seas where there is no perceptible tide, the winds and waves gradually form a fringe of drifted matter, so that in either case there is impressed upon the land a water-mark which it is im-

possible to mistake for any other appearance. Where an elevation of the land takes place, this beach will form a terrace composed of sand, gravel, and other marine debris, ranging more or less parallel with the new line of coast: such terraces are known by the name of *raised or ancient beaches*. But the earth's crust is as liable to depression as elevation; and though depressions are not so obvious, in consequence of the overflow of the ocean, still, in certain localities, the ebbing tide exposes the stumps of trees and other terrestrial evidences of these districts having at one time formed dry land. Phenomena of this kind are known as *submarine forests*, and are classed with ancient beaches, as showing the depressing and elevating forces to which the terrestrial crust is still subjected.

264. *Raised beaches* have been discovered in many parts of the world; in some, evinced by a single terrace, in others, by a succession of terraces. Several of these beaches are comparatively recent—as the Chili upheave of 1822, and the Ullah Bund at the mouth of the Indus in 1819 (par. 74)—and are obviously the results of local earthquakes and volcanic eruptions. Others are of more ancient date, though still coming within the historic period; while most of the higher terraces evidently belong to the dawn of the present geological era. Examples of such phenomena occur in the valleys of the Forth and Clyde, and along many parts of the coast of Scotland. One terrace, ranging from 40 to 60 feet above the present sea-level, is very continuous, and contains the shells of the limpit, whelk, cockle, common buccinum, and other existing species. It forms the plateau on which many of our modern sea-ports are situated, and preserves an outline generally parallel with the existing shore. Traces of a lower terrace, ranging from 6 to 15 feet above the present high-water mark, occur at several points on the eastern coast; but doubts are entertained whether it might not be the result of other causes than terrestrial elevation. As in Scotland, so in England evidences of a former sea-beach have been detected along the coasts of Lancashire, Yorkshire, and Durham, in the valley of the Mersey, and in the Bristol Channel. The same terraced appearances, with the remains of existing sea-shells, are found on the coasts of France, Portugal, Sicily, Greece, Norway, Sweden, and other parts of the European sea-board. In the Mediterranean, one terrace, nearly 50 feet above the sea, and full of shells, is discernible at many distant parts of the shore; on the coast of Norway, accumulations of marine shells are found nearly 200 feet above the existing beach; and along the borders of the Baltic, well-defined plateaus of marine detritus occur at elevations varying from 50 to 100 feet. All

these examples, with many others which might be adduced from the coasts of South and North America, point to successive elevations of the land, analogous to those by which the stratified formations were raised from their seas of deposit into open day. The remains found in the gravel and sand of these beaches are chiefly shells belonging to *species* now inhabiting the ocean, though a careful examination detects *varieties* apparently extinct. The more elevated terraces, like those of Scotland and Scandinavia, are evidently of great antiquity, and where they occupy wide expanses in ancient firths and bays, are apt to be mistaken by the superficial observer for true diluvial or even tertiary gravels.

265. *With regard to the origin of submarine forests*, geologists are somewhat at variance—one class of theorists advancing such phenomena as evidences of submergence, another contending that they merely occupy low flat districts, which have been successively lost and won by the sea. Without advocating either hypothesis, it may be stated that the sites of these so-called forests are generally flattish districts a few feet under the ordinary sea-level, and when exposed after a storm, or during ebb tides, present a series of half-fossilised stumps, with their roots imbedded in a stratum of dark-blue clay, evidently the soil in which they grew. The stumps have undergone various degrees of petrification, and many of them are also incrustated with iron pyrites. Phenomena of this kind have been detected in the estuary of the Tay, in the Firth of Forth, on the coast of Hampshire, and other places—proving, to all appearance, that the land in which they grew had been submerged beneath the ocean. Those who oppose this view, suppose the trees to have grown in low alluvial tracts, which were sheltered from the inroads of the sea by sandhills and other barriers, and that on these barriers being broken down, the forests were overthrown, and their trunks and roots covered by the inundating waters of the ocean. This latter hypothesis, however, has few adherents, the *submergence* of land being as common a phenomena as its *elevation*. Submergences, like those of the Japanese towns in 1596, of Port Royal in 1692, of parts of the Portuguese and African coasts during the Lisbon earthquake of 1775, are occurrences to which all districts have been and are still liable; and there is nothing more unusual in detecting the stumps and roots of trees on the bed of the ocean, than in perceiving the houses of Port Royal, which were visible for nearly a century after their submergence.

266. *The conclusion to be drawn from the occurrence of raised beaches and submarine forests* is, that the crust of the earth is still subjected to the same elevating and depressing forces which

were instrumental in modifying its surface during the deposition of the earlier formations. The results of existing forces may be insignificant when compared with those of former periods, but they are precisely analogous. An elevation of 100 feet may produce a very narrow terrace of gravel, where the land shelves rapidly beneath the water; but where the sea is shallow, as in most bays and estuaries, it will lay bare thousands of acres composed of mud, clay, sand, gravel, and marine exuvæ. A new formation would thus be constituted as peculiar and as characteristic of its era and origin as the tertiary or any other system of strata.

MARINE SILT, SAND-DRIFT, SHINGLE BEACHES, &c.

267. Under the term "*Marine Silt*" is comprehended all those masses of sand, mud, clay, gravel, &c. which are still in progress of accumulation along the existing shores of the ocean. Waves, tides, and other oceanic currents, are the forces by which they are collected and arranged, although a great, perhaps the greater, proportion of the material is derived from the land by the ceaseless transport of streams and rivers. It is necessary, however, to form geological distinctions between marine, estuary, river and lake deposits, as far as practicable, according to the agency more immediately concerned in their aggregation; for it is only by so doing that we are enabled to account for the peculiarity of their organic remains, and therefrom to form correct ideas respecting the character of the earlier formations. Along the entire shore of the ocean, drifted matter is always more or less accumulating; scantily around headlands and exposed places, where the sweep of the tidal current is powerful; abundantly in sheltered bays and recesses. Of the extent of such deposits it is impossible to form anything like a correct estimate, travellers and voyagers having hitherto directed little or no attention to the geological features of the countries which they visit. Instances of marine silt are afforded by the sands of Tentsmoor and Pilmoor between the Tay and St Andrews in Scotland, by the "warp" yearly reclaimed near the mouth of the Humber, the fens of Lincoln and adjoining counties, the extensive sands and marshes near Yarmouth, the Chesil bank at Portland, and the flats of Somerset and Gloucester on the estuary of the Severn. Some of these tracts are of considerable extent; but they are insignificant compared with what has taken place in other regions. The isthmus of Suez, for example, which is now 27 miles broad, is said to have doubled its width since the time of Herodotus (4000 years ago); Tehama, a country on the Red

Sea, has increased from three to six miles seaward since the Christian era; Tyre and Sidon, sea-ports mentioned in Scripture, are now several miles inland; hundreds of square miles of Holland, and the other Low Countries of the continent, are the direct formation of the existing seas.

268. *Sand-drift* is so intimately connected with marine silt, that both may, without much impropriety, be considered as one deposit. When the latter is chiefly composed of sand and comminuted shells, its surface, on being exposed by the ebbing tide, becomes so dry and light as to be easily borne about by the wind. Blown into slight eminences and irregular ridges, a portion of it is placed beyond the reach of the returning tide, and this process, repeated year after year, gives rise to extensive flats of sand curiously blown into *dunes* or little hillocks, and scooped out into hollows or *bunkers*. The seeds of the *arundo arenaria* (bent), *elymus*, and other maritime plants, soon spring up from this newly-acquired land, and bind it together by their long interweaving roots; other species succeed; and thus, in process of time, a vegetable sward gathers over it, and protects it from farther removal. Such accumulations are known by the name of *sand-drift*, and are of all ages, from that covered by many inches of vegetable soil, and brought under the plough of the farmer, to the loose sand which was drifted up during the ebb of the latest tide. Considerable tracts of this sandy formation are to be found skirting the coasts of every country—at some places in long narrow fringes, at others in wide expanses of many thousands of acres. It is always at the head of bays, in creeks, and other recesses, sheltered by some headland from the sweep of the tidal current, that such deposits occur; indeed, by the erection of artificial jetties or projections, fringes of sand may be collected along the coast of any tidal sea. The difficulty of preventing tracts of this nature from shifting and drifting about, and the damage which follows to cultivated soil by sand being blown over it, has given rise to many schemes for their retention. The common bent (*arundo arenaria*) is regularly planted on the sandy plains of Poland, and Lord Palmerston has followed the same process with complete success on a large tract of sand-drift between Ballyshannon and Sligo in Ireland. The French government plants and protects forests of sea-pine, to prevent the sands of the Bay of Biscay near the Garonne from being drifted inland; and at one time it was held penal to pull the bent which grew upon the *links* or *downs* of Scotland.

269. *Shingle beaches* are those accumulations of rounded and water-worn stones which are piled up on certain parts of the

coast by the conjoint action of the waves and tides. They occur only along exposed districts, from which the sand and finer debris is swept onwards to the more sheltered recesses. The battering force of the waves during high storms is so powerful, that masses of shingle are often found from 4 to 12 feet above ordinary tide-mark—leaving appearances very perplexing to the geologist who is unacquainted with the force of waves, the weight which stones lose when immersed in water, and the curious wedge-like arrangement which takes place among the individual pebbles. In addition to the forward motion imparted to these beaches by the waves, they are also subjected to the lateral current of the tides; and thus some of them move onward along the coast with so perceptible a motion, that they have been designated *travelling beaches*. Where shingle is found at considerable altitudes, or in places now removed from the sea, it is apt to be confounded with diluvial matter; but an attentive examination of the manner in which it is piled up, and the remains which it contains, will prevent such a mistake.

270. *The fossils imbedded in marine silt, sand-drift, and shingle*, all belong to existing races, though some of these races are now extinct in the countries where their remains are found. Marine silt, in many places, must be as ancient as the time when the land and sea received their present configuration; and from the peculiar nature of its formation, must contain both land and marine relics—the latter, however, greatly prevailing. Scarcely any of the fossils are petrified; most of them retain their usual structure; and unless where the sands are highly calcareous or ferruginous, there is no such thing as induration among the materials which compose these deposits.

SUBMARINE DEPOSITS AND ACCUMULATIONS.

271. *Submarine deposits* are those which take place under the waters of the ocean, and are not subjected in any measure to littoral influences. Of such deposits geologists know scarcely anything with certainty, as few seas have been sounded with a view to detect the nature of the material accumulating beneath. This only we know, that where soundings have taken place, mud, sand, shells, broken corals, &c. have been found, evidently deposited there by submarine currents, which are modified in their velocity according to the inequalities of the bottom. Many of these currents are ascertained, and according to the regions whence they come, and over which they pass, so will the material

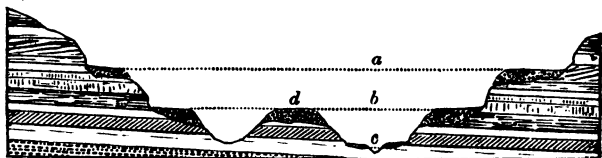
be which they are depositing along the bed of the ocean. Thus, the two polar currents, as they direct their course to the equator, carry with them icebergs and floes laden with the rocks and gravel of the arctic and antarctic islands; the gulf stream transports the sea-weeds, animal remains, and other debris of equatorial countries; while the outward current of the Mediterranean deposits in the Atlantic the products of its temperate regions. All these agents are unceasingly at work; and thus strata are now in formation along the bottom of the sea which, if elevated into dry land, would vie in extent with many of the secondary systems.

272. *Submarine accumulations have been detected in the Yellow Sea, which is rapidly shoaling, in the Gulf of Mexico, in the Caribbean Sea, the German Sea, and in other divisions of the great ocean.* The latter, according to Mr Stevenson, is deepest on the Norwegian side, where the soundings give 190 fathoms; but the mean depth of the whole basin may be stated at no more than 31 fathoms. The bed of this sea is traversed by several enormous banks, one of which, occupying a central position, trends from the Firth of Forth in a north-easterly direction to a distance of 110 miles; others run from Denmark and Jutland upwards of 105 miles to the north-west; while the greatest of all—the Dogger bank—extends for upwards of 354 miles from north to south. The superficies of these enormous shoals is equal to one-fifth of the whole area of the German Ocean, or about one-third of the extent of England and Scotland. The average height of the banks measures about 78 feet, the upper portion of them consisting of fine and coarse siliceous sand, mixed with comminuted corals and shells. As in the German Ocean, so in all other seas agents are at work depositing, however slowly, materials which are destined to form part of the stratified formations of future continents and islands.

TERRACES IN VALLEYS.

273. *Terraces on the sides of valleys, like those along the sea-coast, indicate levels formerly occupied by water.* The latter are ancient sea-beaches, supposed to be the result of elevations of the land; the former may arise partly from elevations of the same nature, and partly from their rivers having cut for themselves a deeper channel. Thus, a terrace in an estuary or river opening towards the sea may be considered as indicating a raised beach; but terraces inland, and above the level of this beach, undoubtedly owe their origin either to the drainage of lakes, or the deepening of river channels.

River-terraces are in general of no great breadth, but sweep along the sides of the valley, looking at a distance like a road embankment; hence the term "parallel roads" has been applied to those observed in Glen Roy. Their surfaces are covered to a considerable thickness with sand and pebbles—showing the long-continued action of water at that elevation. In some valleys there are two or three successive terraces (see fig.), marking the gradual declension of the rivers to their present level; and not unfrequently isolated mounds of gravel (*d*) stand out in the plain, of the same height with some of the terraces, as if these knolls had been shoals and sandbanks when the water occupied a higher level.



a, Upper terrace; *b*, Lower terrace; *c*, Existing river; *d*, Isolated mound of gravel, of the same height with the lower terrace.

274. *Such terraces are found indiscriminately in all parts of valleys—at their heads, in their broad expanses, and in their estuaries. They are frequent where rivers descend from mountainous districts, but not very distinct and definite even should the water have formed glens and valleys of erosion many hundred feet in depth. The reason of this is, that the sides are so steep, so liable to landslips and other waste, that the terraces gradually become obliterated, leaving the bank as one continuous inclination. On the sides of valleys, properly so called, the case is otherwise, the terraces being left level and distinct as on the day they were deserted by the waters. These appearances would seem to indicate the existence of ancient lakes and other accumulations of water at a high level, which were either suddenly or gradually drained as the river cut through the barriers which produced them. Indeed, most of the valleys in our own island appear to have been at one time mere chains of lakes and morasses, now drained in consequence of the waters which flowed from them having gradually deepened their channels. This natural process of drainage is still going forward amid the swamps and lakes of other countries; and it is therefore easy to conceive how terraces, beaches, or ancient water-marks are formed, and will continue to be formed, until rivers have worn down their*

channels to the lowest depth which the relative level of sea and land will permit. Instances occur in Glen Roy, in the valleys of the Tay, Eden, Tyne, Wear, Tees, Ouse, and other British rivers, all of which present the same level shore-like appearance. Similar terraces or *benches* are found extending along large tracts in the vicinity of the great American lakes—showing that these “fresh-water seas,” as they are not inappropriately termed, at one time occupied a higher level, and spread over much wider areas.

DEPOSITS IN VALLEYS.

275. *Deposits in valleys*, as distinguished from those in lakes and estuaries, are of a very complex description. In general, they consist of clay, marsh-silt, sand, gravel, and shingle—according to the nature of the country through which the river flows. Rapid streams leave along their banks only the heavier stones and gravel, and carry all light and impalpable matter to their embouchures. Sluggish rivers, on the other hand, deposit a great portion of their suspended impurities in the valleys through which they flow, thus forming inland tracts of alluvial soil. All rivers, however, are liable to sudden freshets, and as they wind and bend their way seaward, they tear up formerly-deposited matter—here piling up masses of shingle and boulders, there mounds of sand, and again overlaying the whole with a covering of mud. It is therefore impossible to say what was accumulated by the ordinary and what by the extraordinary operations of rivers, or to separate the ancient from the modern. Again, most of our valleys (locally termed dales, haughs, carse, &c.) have been the sites of lakes and morasses in which heterogeneous silt was deposited, and there is thus an insuperable difficulty in distinguishing between what is really fluvial and what lacustrine.

276. *Without making too nice distinctions*, river deposits may be described as more heterogeneous in their material, and more irregularly laid down, than those of lacustrine origin. In lakes, the gravel, sand, and mud are distributed in layers according to their respective gravities, whereas the shingle, gravel, and mud collected by river-torrents are piled up without respect to any law of sedimentary arrangement. Notwithstanding this, there are valley-deposits which it is impossible to ascribe either to the one agency or to the other; and all that the geologist can do, is merely to describe the composition and the nature of the organic remains which may be imbedded therein. Of these accumulations, many are of

great antiquity, and contain bones of the mammoth, elk, deer, horse, ox, bear, wild bear, wolf, and other animals now extinct in the regions where their relics are found ; others are still in progress, connecting the present with the past ; while some are now far removed from the agencies by which they were formed—the rivers having shifted their channels to give birth to newer formations.

DELTA AND ESTUARY DEPOSITS.

277. *Of modern deposits, those formed in estuaries are the most perplexing to the geologist*, on account of the numerous and often opposite agencies concerned in their production. The prevailing agent is the river at whose mouth they are accumulated ; and this brings down mud, sand, gravel, vegetable debris, and the remains of terrestrial animals—during quiet periods the most impalpable silt, during inundations the most heterogeneous mixture. Further, the deltas of rivers subjected to periodical inundations constitute, during the dry season, low flat tracts full of swamps, lagoons, and mud islands, which nourish the rankest jungle growth, gigantic reptiles and amphibia, beds of shells, and shoals of fishes. During the wet season many of these plants and animals are swept seaward, or buried *in situ*, by the debris brought down by the current. Again, the sea acts in most of these estuaries, running inland from ten to a hundred miles, and consequently depositing marine detritus and marine organisms amid those of a terrestrial and fresh-water character. The student cannot therefore fail to perceive how very complex the nature of such deposits must be, and how necessary it is to exercise caution in pronouncing what agent or agents were concerned in the formation of any individual layer. As in modern estuaries, so in those which existed in former times, and thus the difficulty arises with respect to the alternation of marine and fresh-water strata in tertiary basins, the mingling of fresh-water with marine organisms in the wealden, and the complication of terrestrial, fresh-water, and marine products among the rocks of the coal measures. Bearing these facts in mind, and carefully studying the formation of modern estuary deposits, the geologist is prepared to account for appearances in the older systems of strata, which would otherwise remain unsolved.

278. *Estuary deposits may be said to consist of irregular layers of mud, clay, sand, gravel, and vegetable debris, intermingled with organisms of terrestrial, fresh-water, and marine origin.* When accumulated to such an extent as to constitute dry land, they form rich alluvial tracts of a level and uniform

appearance, decidedly prejudicial to health, but favourable to the growth of the cultivated vegetables. In inland and non-tidal seas, as the Mediterranean, Gulf of Venice, and Baltic, the agency of the rivers prevails, forming deltas and shoals which gradually encroach upon the limits of the seas; but in tidal waters oceanic agencies are also at work, either assisting in the accumulation of estuary silt, or distributing the debris brought down by rivers over areas far removed from their embouchures. The accumulations of this kind now forming are almost as numerous as the streams which enter the sea; but the notice of some of the more extensive is all that the limits of this treatise will allow. And here the student should bear in mind one essential difference between the older formations and those of existing estuaries; namely, that among the former a great uniformity prevails, not only in mineral composition, but in the kind of organic remains which they contain, thus evincing a uniformity of climate and other terrestrial conditions; while among the latter scarcely two deposits present one feature in common. The Ganges, for example, bears down to its delta the spoils of the tropics—palms, canes, tree-ferns, bones of elephants, lions, and tigers; the Nile the scanty aquatic plants of Egypt and bones of the crocodile, the camel, and other domestic animals; the Niger the hippopotamus, rhinoceros, and camelopard of Central Africa; and the Mississippi the pines, buffaloes, elks, and deer of North America. In subsequent ages, should these deposits be elevated into dry land, nothing could be more dissimilar than their organic remains, and yet we know that they belong to one common period of formation.

279. *The most extensive deposits of this class* are those of the Mississippi and Amazon in America, the Po and Rhone in Europe, the Niger and Nile in Africa, and the Ganges and rivers of the Yellow Sea in Asia. The delta of the *Mississippi* is partly of oceanic and partly of fluvial origin, and consists of alternations of blue and reddish clays with vast rafts of buried wood, and remains of the buffalo, elk, deer, jaguar, wolf, fox, and other animals peculiar to northern regions. The plain of the river is from thirty to fifty miles broad, but near the sea it widens to treble that breadth. The whole of this valley, extending for hundreds of miles inland, consists of recent alluvium, which the river is perpetually shifting and re-depositing. The most characteristic feature in the deposit is the rafts of drift-trees brought down every spring, and which, according to Captain Hall, are matted together into a network many yards in thickness, and stretching over hundreds of square leagues. Respecting the material deposited near the

mouth of the *Amazon*, we have less particular information ; but it is stated by Captain Sabine, that its sediment discolours the waters of the ocean three hundred miles off shore. This sediment is constantly carried to the north-west as far as the mouth of the *Orinocco*, and thus an immense tract of swamp is formed along the coast of *Guiana*, with a long range of muddy shoals bordering the marshes—the whole being gradually converted into dry land. Although on a less gigantic scale, the deltoid deposits of *Europe* have, even within a very recent period, made considerable accessions to the land. During the last thousand years, that of the *Rhone* has gained upon the *Mediterranean* from four to six miles. “*Notre Dame des Ports*,” says Mr Lyell, “was a harbour in 898, but is now a league from the shore ; *Psalmody* was an island in 815, and is now two leagues from the sea ; and the Tower of *Tignaux*, erected on the shore so late as 1737, is already a French mile from it.” At the head of the *Adriatic*, the *Po* and other streams have borne down so much sediment, that “from the northernmost point of the Gulf of *Trieste* down to the south of *Ravenna*, there is an uninterrupted series of recent accessions of land more than one hundred miles in length, which, within the last two thousand years, have increased from ten to twenty miles in breadth.”

280. *Turning to Africa : lower Egypt is the gift of the Nile ;* and *Herodotus* estimates the sediments borne down by this river to be so abundant, that if diverted into the *Red Sea*, they would fill it up in ten thousand years. The *Nile* still transports its annual burden of debris, but the seaward growth of the delta is prevented by littoral currents, which sweep it onward to other parts of the *Mediterranean*. The *Niger* presents one of the best examples of modern deltoid deposits, and affords the geologist much insight as to the manner in which terrestrial, fresh-water, and marine remains become imbedded in the same formation. This delta, as yet so imperfectly examined, ranges along the coast for more than two hundred miles, having a beach of sea-sand slightly elevated above its general level. Behind this beach, stretching inland for more than one hundred and fifty miles, there extend vast expanses of swamp, mangrove-jungle, and mud islands, intersected by creeks, lagoons, and branches of the river. Over this expanse (annually inundated for several months) deposits of sand, clay, silt, and mud are constantly taking place, burying within them the remains of rhinoceroses, hippopotami, crocodiles, &c. which inhabit the jungle, terrestrial animals which the current transports from the high country, and myriads of shell-fish and other aquatic races which abound in the lagoons. Here,

then, we have salt-water agencies prevailing for many leagues inland during the dry season ; gigantic amphibia at all seasons ; shell-beds and formations of marl in the lagoons ; terrestrial animals from inland ; jungles and morasses to form lignite ; and sand, mud, and gravel to form sandstone and shale. Should a period, therefore, ever arrive when the delta of the Niger shall become habitable dry land, appearances will present themselves perfectly analogous to the tertiary formation, and one by which a flood of light is thrown upon the formation of the coal measures.

281. *The delta of the Ganges*, according to Major Rennel, is considerably more than double that of the Nile, occupying not less than an area of 44,000 square miles. That portion of it which borders on the sea is composed of a labyrinth of rivers and creeks, all filled with salt-water, except those immediately communicating with the principal branch of the river. This tract alone, known by the name of the Sunderbunds, is equal to the whole principality of Wales ; but from its recent alluvial character, is subject to numerous shiftings, though ultimately settling down and shoaling up the Bay of Bengal. The quantity of sand and mud brought down by the Ganges is so great, that the sea only recovers its transparency at the distance of sixty miles from the coast ; thus not only adding new material to the shoals and islands of the Sunderbunds, but forming immense tracts of submarine strata at various depths from four to seventy fathoms. As Egypt is said to be "the gift of the Nile," so may the great plain of China be considered as the gift of the *Hoang-Ho*, the *Kiang-Koo*, and their tributaries. The same agencies which formed the habitable plain are still at work, gradually shoaling up the Yellow Sea, and converting its basin into solid land. Navigators speak of their keels ploughing up the fine impalpable sediment at a distance of six and eight leagues off shore, along which a perceptible increase is taking place every year. Sir George Staunton infers, from certain experiments, that the *Hoang-Ho* contains one part of sediment in every two hundred ; and estimating the average depth of the Yellow Sea to be one hundred and twenty feet, calculates that this river by itself is capable of converting an English square mile into solid land in the course of seventy days.

282. *From the examples given*, the student will perceive that estuary deposits—that is, deltas or deposits taking place at the mouths of rivers—are among the most important in modifying the present configuration of land and sea ; that they constitute the connecting link between formations now in progress and those of distant eras ; and present appearances which enable

the geologist to infer as to the manner in which the greater portion of the stratified systems were deposited. Their organic remains are numerous ; are partially fossilised, or differ little from recent wood, bones, and shells ; and all belong to vegetables and animals which have been placed upon the earth since the commencement of the present geological era. Where tidal influences prevail, these remains are chiefly marine ; where river inundations predominate, they are fresh-water and terrestrial ; while others, as beds of oysters, &c. are of true estuary origin.

LACUSTRINE, OR LAKE, DEPOSITS.

283. *By lacustrine deposits are meant those accumulations which have been collected in fresh-water lakes since the present order of things was established.* Looking back to certain coal-fields, and to the fresh-water beds of the wealden and tertiary strata, we have almost evidence sufficient to justify the conclusion, that these beds must have been formed in lakes, or at least in estuaries where quiet fresh-water influences greatly predominated. Indeed it is impossible to conceive of a condition of the world without inland lakes, morasses, and swamps, in which aquatic races flourished, shell marl was formed, and peat-moss accumulated. But the boundaries of those ancient lacustrine deposits are now obliterated ; and all that the geologist can do is, to judge of the manner of their accumulation, and the nature of their contents, by comparing them with similar deposits now occupying the surface of the earth, or still in progress of formation.

284. *Modern lake deposits* consist of clay-silt, sand, gravel, rolled pebbles, beds of marl, and accumulations of peat-moss. Generally situated in plains or hollows, surrounded by hills, a lake receives the waters and debris of several streams, and its quiet expanse performing the office of a great settling pool, the debris falls down as sediment, and the waters pass off by one outlet purged of all their impurities. This sediment, collecting at the mouths of the streams, forms little deltas, which gradually push themselves forward into the lake ; aquatic plants soon spring up on their surface, whose annual growth and decay constitute beds of peat ; fresh-water shell-fish and the calcareous debris of the springs and streams collect in certain localities as marl ; and these various formations repeated and continued, in process of time shoal up the lake, which forms a flat alluvial tract, swampy at first, but soon acquiring firmness and dryness for the purposes of cultivation. Silted-up lakes are rife in this country as well as in

other parts of the world ; they occupy the central and wider parts of our dales and valleys ; and though all superficial evidences of the lake be obliterated, the regular manner in which the materials are distributed serve readily to distinguish lacustrine from fluvial silt. Respecting the extent of surface occupied by lake deposits, it is impossible as yet to form an accurate estimate, though it is evident that the soil of most inland valleys, both in this and in other countries, is composed of it. The prairies of North America, the pampas of South America, and the steppes of Europe and Asia, are regarded by many as the sites of lakes now drained or silted up ; and, considering their relation to existing rivers and valleys of drainage, there is ample foundation for the opinion. Considerable tracts of alluvial land are still in progress of formation along the borders of most modern lakes, whose sites, under the double process of silting up and drainage, are evidently destined to become alluvial plains like those to which we have adverted. By *drainage* is meant that tendency which rivers issuing from lakes have to deepen their channels, and thereby not only to lower the level of their parent waters, but also to render them, from their shallowness, more liable to be choked up by aquatic vegetation.

285. *Of the various substances composing lake deposits*, marl is the only one whose formation deserves particular notice. This substance may be looked upon as the *limestone* of the superficial accumulations, just as the chalk, oolite, lias, zechstein, mountain limestone, and cornstone, were the calcareous beds of their respective formations. It occurs in various states of purity, from a marly clay, which will scarcely effervesce with acids, to a shell-marl containing from 80 to 90 per cent. of lime. *Marl-clay*, for instance, occurs as a whitish friable clay with an admixture of lime, and sometimes also of magnesian earth ; the term *clay-marl* is applied when the calcareous matter prevails over the clay ; *shell-marl* is almost wholly composed of lime and fresh-water shells, with a trace of clay or other earthy matter, and, where solidified by chemical aggregation, is known as *rock-marl*. With respect to the origin of these marls there are various opinions, though it is generally admitted that they are derived partly from calcareous springs which enter the lakes, and partly from the shells and secretions of the fresh-water molluscs which inhabit them. What tends to confirm this opinion is the fact, that marl-clay and clay-marl are found chiefly among the deposits of ancient or modern lakes situated in limestone districts where calcareous springs abound ; and that shell-marl is often almost wholly composed of the exuviae of molluscs, many genera of which

are still inhabiting the same lakes and marshes in which the deposit is found. Marl occurs irregularly interstratified with clay-silt, peat-moss, or gravel, and is dug for agricultural purposes in many of the ancient lake-sites and alluvial valleys of Britain.

286. *The organic remains found in lacustrine deposits* are chiefly fresh-water shells, such as *limnæa*, *planorbis*, *paludina*, *cyclas*, *mya*, *cypris*, *ancylus*, &c.; bones, horns, and other portions of *mammalia*, as the stag, elk, deer, ox, horse, bear, fox, beaver; detached skeletons of *birds*; and drift or submerged *plants*, of which oaks, pines, birches, hazels, reeds, rushes, and other vegetation commonly found in peat-mosses, are the most abundant. Human skeletons are occasionally met with; and canoes, stone battle-axes, &c. of great antiquity have been dug up from the silt of Loch Doon in Ayr, as well as from the shell-marl of Kinnordy Loch in Forfarshire. All of these remains, whether plants or animals, belong to races now existing upon the globe, although some genera (as the elk, wild-boar, and beaver in Britain) may have become extinct in the regions where their exuvie are found.

EXPLANATORY NOTE.

EMBOUCHURE—a term adopted from the French, signifying the mouth of a river, or rather that area over which its current spreads as it enters any sea or lake.

FRESHETS, OR LAND-FLOODS, are sudden risings of rivers, by which they inundate their banks, and carry destruction before them. The term *debacle* (from the French *debacler*, to unbar) is often used instead; but more properly means a rush of water, breaking down all opposing barriers, and carrying away and dispersing fragments of rocks and other debris.

VALLEYS OF EROSION are those which have been formed by the abrading power of water. Rivers having a rapid descent gradually deepen their channels; year after year their banks are undermined, and fall into the current, until they have acquired a slope sufficiently gentle to render them stable; but this stability is only temporary, for the deepening of the channel goes forward, causing the bank to assume a still more gentle slope, till in time a valley of considerable width is formed. Such are termed *valleys of erosion*, in contradistinction to those produced by the silting up of chains of lakes, called *flat valleys*, to those caused by subterranean sinkings, called *valleys of depression*, or to those originally formed by rents and *fissures* resulting from earthquakes.

LAGOON (Lat., *lacuna*, a morass) — a term originally applied to those creeks and pools which abound along the coast of the upper Adriatic; but now employed to designate all similar collections of water, in whatever region they occur. Lagoons are sometimes of considerable depth (those enclosed by circular coral islands); but generally they are so shallow (those of deltas) as to emit noxious exhalations.

STEPPIES—the Russian name given to the vast system of plains peculiar to Northern Asia. It is synonymous with the *prairies* or *savannahs* of North America; and the *pampas* or *llanos* of South America. These plains are variously classified, according to the level, undulating, or swampy character of the surface, the kind of vegetation they produce, and other obvious appearances.

SUPERFICIAL ACCUMULATIONS—CONTINUED.

CHEMICAL AND MINERAL DEPOSITS.

287. *Under this head are comprehended all those superficial accumulations of mineral, saline, or bituminous matter arising from the action of springs, evaporation, sublimation, or other natural chemical processes. Such products are extremely numerous; but only a few of them exert a perceptible influence in modifying the crust of the globe. Calc-tuff and calc-sinter are deposited by calcareous springs after the manner described in par. 58. The former, as the name tuff or tufe implies, is a porous vesicular mass, soft when first deposited, but becoming hard on exposure to the air, so as to resemble marble or alabaster. It is generally of a yellowish-white, and encloses moss, twigs, shells, fragments of bones, and other debris that may be brought within reach of the spring by which it is deposited. The latter, from the German word sintern, to drop, or from sinter, a scale, is more compact and crystalline, and has a concretionary structure, owing to the successive films which are daily added to the mass. Both are found around the sources and edges of calcareous springs, sometimes spreading to a considerable extent, and not unfrequently investing high cliffs with a crust of unrivalled splendour. Stalactite and stalagmite are kindred productions, both being produced in calcareous caverns by the dropping or oozing of water. The former (Gr., stalaktis, anything which drops) are those pendants of carbonate of lime which hang from the roofs of caverns like icicles; they are formed by the slow dropping of calcareous water. The latter (Gr., stalagma, a drop), on the other hand, are the crusts and protuberances produced on the floors of such caverns. Sometimes the stalactites and stalagmites meet, forming pillars and arches which seem to support the roof. Caverns adorned in this manner occur in Derbyshire, in the islands of Paros and Antiparos, and in other parts of the world, and have been described by travellers in the most fascinating terms. Taverine (a corruption of the word Tiburtinus) is another calcareous incrustation, deposited by water holding carbonate of lime in solution. It is abundantly*

formed by the river Anio at Tibur, near Rome, at San Vignone in Tuscany, and in other parts of Italy. It collects with great rapidity, and becomes sufficiently compact in a few years to form an excellent building stone. "A hard stratum," says Mr Lyell, "about a foot in thickness, is obtained from the waters of San Filippo in four months; and as the springs are powerful, and almost uniform in the quantity given out, we are at no loss to comprehend the magnitude of the mass which descends the hill, which is a mile and a quarter in length, and the third of a mile in breadth, in some places attaining a thickness of 250 feet. To what length it might have reached it is impossible to conjecture, as it is cut off by a stream which carries the remainder of the calcareous matter to the sea." Tavertine is a light, porous, or concretionary rock, well adapted for arches and other structures where weight is objectionable; it is for this reason that it has been used in the construction of the cupola of St Peters.

288. *Silicious and aluminous deposits* derived from springs are of very limited extent—those produced by the Iceland geysers, and the thermal waters of the Azores, being the only examples deserving of notice. According to Dr Webster, the hot springs of the Valle das Furnas, in the island of St Michael, rises through volcanic rocks, and precipitates considerable quantities of silicious sinter. Around the circular basin of the largest spring there are seen alternate layers of coarse sinter mixed with clay, including grasses, ferns, reeds, &c. in different states of petrification. Wherever the water has flowed, sinter is found rising eight or ten inches above the ordinary level of the stream. The herbage and leaves are more or less incrustated with silice, and exhibit all the successive stages of petrification, from the soft state to a complete conversion into stone; but in some instances *alumina* is the mineralising material. Fragments of wood, and one entire bed, from three to five feet in depth, composed of reeds common to the island, have become wholly silicified; and a breccia is also in act of formation, composed of obsidian, scorise, and pumice, cemented by silicious sinter. The same kind of appearances are produced by the geysers of Iceland and several other thermal waters. Where alumina and silica are held in solution by the same spring, the deposit produces an admixture called *tripoli*, so named from Tripoli in Barbary, where a similar compound of silica, alumina, and oxide of iron is abundantly obtained for polishing purposes. All the varieties of tripoli do not seem, however, to be derived from the same source; for Ehrenberg has found the flinty portion of several varieties to be composed of the silicious coverings of animalcules. The fact of hot springs

holding silica in solution, its converting organic matter into flint, and forming layers of tripoli and sinter, is of high importance to the geologist, as it furnishes him with data to reason respecting the origin of the chalk-flints, the occurrence of layers and nodules of chert in limestone, and other appearances among the older stratified systems.

289. *Bituminous exudations*—that is, springs of naphtha, petroleum, &c.—are very abundant in some countries, forming pools of fluid pitch and consolidated masses of asphalt, and impregnating layers of sand, clay, &c. so as to render them inflammable. Naphtha, the most limpid of the bitumens, is found exuding from the earth upon the shores of the Caspian and some other Eastern countries. Near the village of Amiano, in the state of Parma, there exists a spring which yields this substance in sufficient quantity to illuminate the city of Genoa, for which purpose it is employed. It is generally of a yellow colour, and is readily distinguished from other bitumens by its peculiar odour. Springs of *petroleum*, or rock oil, are found in Modena, Parma, Sicily, and other parts of Europe, in Syria and Persia, in the Burman empire, in Texas, and in Barbadoes, whence the appellation *Barbadoes tar*. It is a brown thickish liquid, and in this state readily mingles with loose rocky substances, so as to render their mass bituminous. On exposure to the air it becomes viscous or sluggy, and then constitutes *mineral pitch*, of which the lake of Trinidad, and that of Jefferson county, Texas, are well-known accumulations. *Asphalt* differs from mineral pitch in being so much consolidated as to be rendered brittle. It is found on the surface and banks of the Dead Sea, in Trinidad, Barbadoes, and other localities. It is supposed that these products are sublimed or distilled from bituminous rocks in the solid crust by the power of subterranean heat, and gradually make their way through chinks and fissures to the surface. Whatever be the source from which they are produced, the manner in which they mingle with the layers now forming in the bottoms of lakes and seas, furnishes the geologist with analogies which may aid him in accounting for the occurrence of bituminous strata in which no traces of vegetation can be detected.

290. *The economical uses of the bitumens* are too well known to require much detail. Asphalt was extensively used by the ancients as a cement; hence the name, which is derived from the Greek, *a*, not, and *sphallo*, I slip—that is, something to stick together with, or prevent from slipping. It is now used extensively in the manufacture of materials for roofs, linings for water-cisterns, foot-pavements, &c. Distilled naphtha is

extensively employed as a solvent for caoutchouc, and is also occasionally used as a substitute for oil in lamps.

PEAT-MOSSES—JUNGLE—VEGETABLE DRIFT.

291. *Modern vegetable formations* are commonly distinguished as subterranean forests, peat-mosses, jungle, and vegetable drift, though it must be evident that in many cases no real distinction can be drawn between them. *Submarine forests* have been already noticed (par. 265) as evidences of terrestrial submergence; *subterranean forests* are those accumulations of trunks, branches, and roots which occur inland, apparently produced by the inundation and subsequent silting up of low-lying tracts, in which trees flourished abundantly. But as the subsequent silt is most abundantly composed of aquatic and other peat-forming plants, subterranean forests and *peat-mosses* may be regarded as depending upon the same agency for their production. It must be remembered, however, that peat-bogs and mosses of very great extent are to be found in northern countries entirely destitute of trees, having been formed by the annual growth and decay of the *sphagnum palustre* and other marshy vegetation. With respect to the amount of vegetable matter derived from tropical *jungles*, no accurate information has yet been obtained, though analogy would warrant the conclusion that the result is too important to be overlooked by geologists. The same may be said of *vegetable drift*, of which the rafts of the Mississippi, already adverted to, afford a striking example. It is therefore to subterranean forests and peat-mosses that the attention of the student is chiefly directed, these being by far the most extensive of modern vegetable formations.

292. *Subterranean forests* are found in estuaries now silted up, in ancient lakes, and under ordinary peat-bogs. When they occur in estuaries or in low alluvial lands adjoining the sea, they would seem to have been drifted from inland by river inundations; for most of the trunks and branches lie in such a position as to forbid the supposition that they grew in these situations. "A very interesting case of this kind," says Professor Phillips, "was exhibited some years ago by the deep cutting of a canal connected with the Aire and Calder navigation. At a depth of twelve feet from the surface of the fine alluvial sediment, here occupying the broad valley of the Aire, a quantity of hazel bushes, roots, and nuts, with some mosses, fresh-water shells, and bones of the stag, were met with. In some parts of the superjacent sediments an English coin was found, and oars of a boat were dug up. Where a

little water entered this peaty and shelly deposit from the adjacent upper magnesian limestone, it produced in the wood a singular petrification; for the external bark and wood were converted into carbonate of lime, in which the vegetable structure was perfectly preserved. In like manner some of the nuts were altered; the shell and the membranes lining it were unchanged; but the kernel was converted into carbonate of lime, not crystallised, but retaining the peculiar texture of the recent fruit. In this particular case no reasonable doubt can exist that the peaty deposit, full of land mosses, hazel bushes, and fresh-water shells, was *water-moved*, and covered up by fine sediments from the river and the tide." As with the example now quoted, so with numerous accumulations of trunks, roots, and branches of trees found in silted-up estuaries and in heads of bays both along our own coasts, the shores of the Baltic, and other sea-boards. Most of them have evidently been drifted thither by rivers and tidal influences, although forests in some low tracts may have been overthrown and buried by inundations of the sea. When subterranean forests occur beneath lake deposits, or under ordinary peat-bogs, they point to causes by which the drainage of low woody valleys has been choked up, and their surfaces covered with water, so as to destroy the trees, and bury them by subsequent accumulations of silt and peat-growth.

293. *Peat—or turf, as it is often called—is a natural accumulation of vegetable matter, varying in age from last year's growth to that which was formed several thousand years ago, and in appearance from a loose fibrous mass of a brown colour to a dark and compact substance resembling lignite or brown coal. It is forming in all marshes by the annual decay of aquatic vegetation, and is encroaching upon shallow lakes by a similar process. The plants which enter most abundantly into its composition are the sphagnum palustre, or "peat-plant," a number of mosses, rushes, reeds, and other marsh-loving tribes, crowned in some situations by heather, to whose antiseptic properties De Luc ascribes the conservation and accumulation of the other vegetable substances. Formations of peat have been variously classified: thus, common peat, composed of the stem, leaves, and roots of marsh plants; woody peat, derived from the branches, leaves, trunks, and roots of trees; peat-turf, the heathy turf which covers moorland districts; hill-peat, when formed on the sides of declivities; and peat-bog, when it accumulates in hollow places, or on flat marshy surfaces. Whatever distinctions may be made, the main facts connected with their formation are the same—they are individually the result of decomposed vegetation accumu-*

lated under certain conditions and in particular localities. They are to be met with in almost all temperate and cold moist countries, whether in the northern or southern hemisphere. They occur abundantly in Scotland and England, and constitute a large proportion of the surface of Ireland. They occupy vast tracts in the Netherlands, Germany, and Russia, as well as in North America and Canada, and are to be found in insular regions, as Shetland, Iceland, and the Falkland Islands. Of the absolute surface occupied by peat, we have no accurate estimate; but some idea of the geological importance of the formation may be formed from the fact, that one of the mosses on the Shannon is fifty miles long, and from two to three in breadth, while the great marsh of Montoire, near the mouth of the Loire, is not less than fifty leagues in circumference. Some of the Scottish mosses have been dug for fuel to the depth of twenty feet, and many in Ireland are reckoned at twice that thickness. It must be borne in mind, however, that nearly one half of the bulk is made up of water, and that the mass can be reduced by compression to less than a fifth of its original thickness.

294. *The formation of peat*, as has been stated, is confined to moist situations, where the temperature is low, and where vegetables may decompose without putrifying. It is thus found in swamps, and on declivities where springs abound, almost entirely composed of marsh plants; in the sites of ancient lakes, covering layers of gravel, marl, silt, &c. and mingled with earthy impurities; or in low tracts whose drainage has been choked, burying, and in part formed of, the trunks and branches of trees which flourished upon those spots previous to their inundation. It increases with astonishing rapidity, instances having been known where fifteen inches in thickness had been formed in twenty years. Being light and spongy, fully half its bulk is composed of water, and this retentive quality enables new races of plants to flourish long after the surface of the moss has been raised above the drainage-level of the flat in which it occurs. When the mass has sufficiently accumulated to change its character from that of a shaking morass to a firm peat-bed, the marsh plants die out, and are succeeded by heath and other vegetation, which carry on the process of accumulation at a less rapid but still perceptible rate. Such is the ordinary mode of peat-growth, concerning which there can be no difference of opinion, for many of the accumulations are still in progress; but respecting those collections of trees which are often found buried in the mass, geologists are far from being agreed. From the varied situations in which such collections occur, as well

as from the different positions in which the trunks are found in the mass, it is evident that different agencies have been at work in their aggregation. In river valleys, the trees sometimes appear to have been drifted, and subsequently silted up and covered by peat-growth; in general, however, they have evidently grown where they occur, and been prostrated either by natural or artificial causes. If, for example, the drainage of a wooded valley were obstructed, so as to render the soil wet and swampy, the further growth of the forest would be checked; the trees, deprived of their firm anchorage in the ground, would be easily overturned by winds; and as they were prostrated, grasses, reeds, and marsh plants would spring up through their branches, and grow rank upon the nourishment afforded by their decay. This prostration of trunks and matting of vegetation would further obstruct the drainage of the waters, so that in process of time the whole of the trees would be overturned, and the valley converted into a swampy morass. In such a morass peat plants would luxuriate till, by their own growth and decay, they reached a height beyond that of the drainage-level, when their accumulation would cease, and a peat-moss be completed perfectly analogous to many of those in Ireland and Scotland. The same result would follow whether the trees were prostrated by natural or artificial causes; and there is evidence afforded by the trunks in many localities that they were felled by man at no very distant era. In the peat of Hatfield Chase, for instance, Roman coins and axes have been found, some of the latter still fixed in the wood; a medal of Gordian was found thirty feet deep in peat at Groningen; and De Luc has ascertained that the very site of the aboriginal forests of Hercinia, Senaar, Ardennes, &c. are now occupied by mosses and fens—a result chiefly brought about by the Emperor Severus, who ordered all the wood in the conquered provinces to be destroyed. From these facts, the student will perceive how necessary it is to examine the mode in which the trunks occur, before the geologist can venture to pronounce as to their collection. If the trees are cut and hewn, man must have been concerned in their prostration; if they are merely broken over, or still attached to their roots, natural causes alone have been at work. In general, the smaller branches have decayed, leaving the trunk and larger limbs, with fragments of the bark and the root, in good preservation. The trees are principally oak, fir, yew, hazel, birch, ash, and willow; they lie prostrated most abundantly towards the east and north-east; and are often of very gigantic dimensions. The greater number seem to have undergone considerable decomposition

before they were fully enveloped in peat-growth; showing clearly that though the whole face of a country were covered by prostrated forests, it would only be in marshes and peat-forming hollows that the trunks could be preserved from utter decay.

295. *Respecting the antiquity of peat-mosses*, we can form a tolerably correct idea from the nature of their imbedded fossils. The most ancient have been formed since the sea and land received their present configuration, and since the latter was peopled by those animals which now inhabit it; for from none have we well authenticated specimens of greater antiquity than the existing elk, deer, wild ox, buffalo, &c. Indeed the greater proportion of European morasses are of comparatively recent formation, yielding the canoes and skeletons of the hair-clothed aborigines—the coins, axes, and other implements of their Roman invaders—the bones and horns of the elk, deer, ox, and other animals with which we are still familiar. Many have even been formed, as it were, but yesterday; for we learn that the overthrow of a forest by a storm about the middle of the seventeenth century gave rise to a peat-moss near Lochbroom in Ross-shire, where, in less than half a century after the fall of the trees, the inhabitants dug peat. Whatever be their relative antiquity, they are all possessed of great interest, from the evidence which they afford of the rapid accumulation of vegetable growth, and from the perfect manner in which their tannin or antiseptic principles have preserved the remains of man and the lower animals. We cannot look upon the vast collection of trees which they contain, without being reminded of a period when Britain was clothed with gigantic forests; on the rude stone hatchets, canoes, and skeletons of men clad in skins, without reverting to the condition of our earlier ancestors; or on the coins, arms, and other implements of the Romans, without associating therewith the means by which a rude and barbarous country was reclaimed to culture and civilisation.

296. *The economical applications of peat* constitute one of its most important features. Cut in rectangular pieces, and dried by the heat of summer, it forms in many districts the principal fuel, not only for domestic use, but for burning lime, heating corn and malt kilns, distilling alcohol, &c. To facilitate the process of drying, the water is sometimes pressed out of the square pieces by a compressing machine, which also renders the material more compact and durable in the fire. Peat is occasionally charred by a smothered combustion, which makes it a more suitable substitute for coal or coke in the smelting of iron and similar purposes. Attempts have also

been made to extract tannin from its mass, to be used instead of oak and larch bark in the preparation of leather. Decomposed peat forms an excellent manure for certain soils, and is now extensively employed in modern agriculture.

SHELL-BEDS, CORAL-REEFS, &c.

297. *The animal accumulations of the present day*, like those of former eras, are chiefly discernible in the exuvæ of shell-fish and coral animalcules. It is true that the remains of fishes, insects, birds, and mammalia, are constantly being entombed in the deposits now taking place; but, in point of quantity, these are too insignificant to constitute an independent stratum. Such remains must not, however, be overlooked, as their presence in any deposit will indicate to future geologists the condition of the world under which the animals flourished, just as the fossils of older formations are the characters by which we can interpret the conditions of the past. Besides the gradual entombment of organisms which takes place in the ordinary course of nature, there are extraordinary causes by which hundreds and thousands of living beings are destroyed and buried in common ruin. The desolation of populous cities by earthquakes, the destruction of flocks and herds by similar catastrophes or by river inundations, the death of shoals of fishes by submarine exhalations, the drowning of clouds of locusts, and the like, will present curious appearances in the accumulations in which they are imbedded; and it is necessary that the student should bear such possibilities in mind, otherwise he might be unable to account for peculiar aggregations of fossils in older strata.

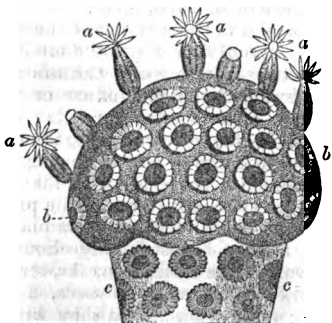
298. *Shell-beds* are accumulations of dead and living shells found under the waters or along the shores of existing seas and lakes. *Dead or drifted* shells are strewn over certain localities in considerable quantities by tidal and other currents; fresh-water varieties are found in lakes constituting beds of marl; and many gregarious species cover large tracts of the bottom of the ocean. Dead shells are thus mingled indiscriminately—genera inhabiting widely different localities, and of the most opposite character, being found in the same mass. A very different arrangement holds with respect to *living* shells, particularly with those of a gregarious character—as the muscle, cockle, and oyster. These live in beds or families, and seem to be governed in their growth and accumulation by circumstances of depth, nature of the bottom, and food, just as terrestrial animals are regulated by climate and other vital conditions. Thus, cockles and muscles delight

in the muddy bottoms of tidal estuaries, where the latter often form beds of two or three feet in thickness, and several miles in extent; while the oyster, at no great depth from the sea-shore, covers the bottom for many leagues, to the exclusion of all other genera. Should such estuaries ever be silted up—and there is ample evidence of like occurrences—these shells would form strata precisely analogous to those beds of shell-limestone which are found among the inferior coal measures, the new red sandstone, and other rock formations. Such, in fact, is the case; and in many estuary and lacustrine deposits shell-beds present themselves partially converted into marl and limestone; while in raised beaches they invariably constitute the most interesting phenomena.

299. *One distinction between the position of ancient and recent shell-beds* requires, however, to be specially adverted to. It has been ascertained that various genera of mollusca live at different depths, constituting zones of marine life analogous to zones of vegetable growth on the side of a mountain. By this distribution certain families are littoral, others live at depths varying from 100 to 600 feet, while few or any are found in 1000 feet water. In general terms: testaceous animals are regulated in their distribution by depth, by the nature of the sea-bottom, and by the influence of submarine currents; the number of families is greatest in shallow waters, gradually decreases as we descend, and finally sinks to zero in the depths of the ocean. Such an arrangement corresponds with all our ideas of vitality: shell-fish can no more subsist under the pressure of extreme depth, absence of light and food, than plants can flourish in the thin cold atmosphere of highly-elevated regions. On examining the crust of the earth, however, strata wholly and partially composed of shells are found covered by many thousand feet of rocks; but as the animals by which the shells were formed could not have existed at such depths, we are led to the conclusion that these shelly beds were formed at moderate depths, that the bottom of the sea was subsequently depressed, and received those sediments of which the overlying strata are composed. Strata destitute of organisms do not therefore prove the non-existence of marine life at the time of their formation; they may have been formed at depths so enormous as excluded the mingling of testaceous remains with their component materials.

300. *Coral reefs*, already adverted to in pars. 85 and 86, are chiefly the production of the coral animalcule, and evince, by their magnitude and extent, the powers of organic agency in modifying the form and structure of the earth's crust. As in the case of the sphagnum palustre and other marsh plants,

whose growth and decay went to the formation of peat-moss, so among corals race after race departs, each leaving its stony skeleton as a foundation for the operations of succeeding races, which are destined to make way in turn for still newer generations. According to Ehrenberg, the coral zoophyte may be regarded as a mere secreting membrane, having the power of separating calcareous matter from the waters of the ocean, wherewith to fashion for itself an internal solid skeleton of carbonate of lime. Around and within the radiated pores of this framework the animalcule lives and propagates its kind, expanding itself in the most brilliant colours during its secreting operations, and contracting and withdrawing itself within the pores when alarmed by danger. Although often exhibiting the most beautiful hues—crimson, blue, and yellow—in their native element, the soft parts, when taken from the sea, become nothing more to appearance than a brown slime spread over the stony framework. These zoophytes swarm in incredible



Mass of *Astraea viridis*; a, a, expanded polypes; b, b, polypes withdrawn into their cells; c, c, stony mass uncovered by flesh.

numbers, and are of many genera and sub-genera—each species building for itself a structure peculiarly fashioned and decorated. According to their forms the various genera are commonly determined, and thus we have such terms as tree, fan, brain, star, and organ-pipe coral, known to the learned by their synonymes—caryophyllia, meandrina, astræa (see fig.), porites, madre-

pora, tubipora, and the like. As with shell-fish, so with coral animals; they do not inhabit extreme depths, but generally carry on their operations along the shores of rocky islands and on the tops of submarine ridges not more than one or two hundred feet under water. Indeed the principal reef builders are rarely found beyond the depth of forty or sixty feet, though solitary branching corals have been dredged in fifty and even a hundred-fathom water. Generally speaking, it would appear that the coral polype has not the power of commencing its structure at great depths, but attaches itself to comparatively shallow points within the influence of those conditions favourable to its development.

301. *Coral polypes in active operation* are thus described by Captain Basil Hall :—"When the tide has left the rock for some time dry, it appears to be a compact mass, exceedingly hard and rugged ; but as the tide rises, and the waves begin to wash over it, the polypi protrude themselves from holes which were before invisible. These animals are of a great variety of shapes and sizes, and in such prodigious numbers, that in a short time the whole surface of the rock appears to be alive and in motion. The most common form is that of a star, with arms or tentacula, which are moved about with a rapid motion in all directions, probably to catch food. Others are so sluggish that they may be mistaken for pieces of the rock, and are generally of a dark colour. When the coral is broken about high-water mark, it is solid hard stone ; but if any part of it be detached at a spot where the tide reaches every day, it is found to be full of polypi of different lengths and colours ; some being as fine as a thread, of a bright yellow, and sometimes of a blue colour. The growth of coral appears to cease when the worm is no longer exposed to the washing of the sea. Thus, a reef rises in the form a cauliflower till the top has gained the level of the highest tides, above which the animalcules have no power to advance, and the reef of course no longer extends upwards."

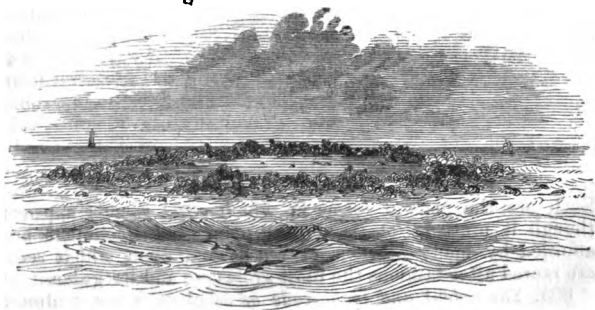
302. *The composition and construction of coral reefs*, though effected chiefly by lime-secreting zoophytes, are still owing, in a great measure, to the promiscuous aggregation of marine debris. As produced by the zoophyte, coral is almost a pure carbonate of lime, soft and porous at first, but gradually becoming so hard and compact as to be used in the South-Sea islands for building. During its formation, however, it encloses shells, fragments of drift-coral, sea-weeds, star-fishes, sea-urchins, drift-wood, and the like ; and these being cemented in one mass by the growth of new coral, as well as by the infiltration of dissolved carbonate of lime, the rock presents a brecciated appearance extremely analogous to some older limestones. Where reefs have been upheaved by subterranean agency, and are now found on the sides of hills partially overlaid by volcanic tufa, the coral stone has a sparry semi-crystalline aspect, thus presenting the geologist with almost every gradation of limestone, from the soft chalky mass of yesterday's secretion to the compact texture of primary marble.

303. *The formation of coral islands* is effected in the following manner :—The polypes having attached themselves to the rocky bottom—say on the summit of some submarine ridge—proceed to build upward and around, till the reef remains

almost dry at low-water level. Here they leave off building in an upward direction, but still proceed seaward, increasing the breadth of their structure, and gradually bringing these additions up to the surface. A continuous mass of calcareous matter is now seen, composed principally of coral, but also abundantly of shells, fragments of crustacea, and other sea-drift. As the waves break upon the new elevation, fragments are detached and thrown up, shells and coral sand are washed upon the reef, and these being cemented together by calcareous matter, form a low ridge exposed to the influences of sun, winds, and rains. In this state rents and fissures take place in the mass, new fragments are detached by the waves, and piled still higher; a perpetual rubbing and grinding of the fragments produces calcareous sand, which is gradually drifted upwards and inwards, filling inequalities, and forming in sheltered recesses a narrow beach. Upon this new territory sea-birds alight, nestle, and leave their droppings; seaweeds and other marine drift are added; a scanty soil is formed; seeds are drifted or borne by birds from the adjacent continents; plants spring up, and in course of years clothe the infant island with vegetation. By this time strayed land-birds have made it their home; insects and reptiles are carried thither upon drifted trees, either alive or in the larva or egg state; and lastly, man appears, and takes possession of the gradually-increasing soil. Such a mode of formation supposes no elevation or submergence of sea-bottom by volcanic action. But in the Pacific, where coral reefs are most extensively developed, subterranean movements are frequent—elevating in some regions, and depressing in others. Thus, a gradual elevation would cause not only a more rapid rise of reef, but would force the polype to operate continually further seaward, so that the mass would assume a broad and stratiform appearance. A gradual depression, on the other hand, would not only lessen the supermarine extent of the reef, but would compel the animalcules to build perpendicularly upwards, instead of laterally, as in the case of elevation. From the peculiar forms which coral reefs assume, it is more than probable that both elevations and depressions are in progress over the bottom of the Pacific; of the former, at least, there is ample evidence in ancient reefs occurring inland and at considerable elevations above the sea. Thus, on the summit of the highest mountain of Tahiti, an island composed almost entirely of volcanic rocks, there is a distinct stratum of fossil coral; and in the Isle of France, a bed ten feet thick occurs between two lava currents.

304. *The various forms which coral reefs present are classed*

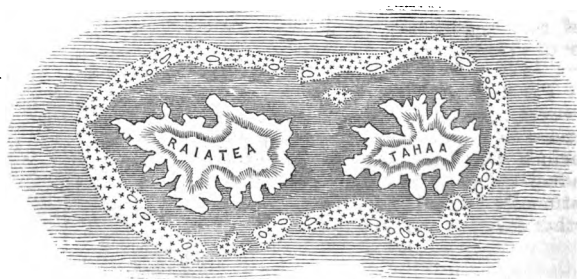
by Mr Stutchbury in the following order :—1. *Circular*, consisting of a strip or belt encircling a lagoon, which communicates with the main ocean by one or more channels ; 2. *Flat*, consisting of a tabular, oval, or irregularly round mass, not intersected by channels or lagoons ; 3. *Long-narrow*, consisting of long narrow ridges or islands, with cross channels at irregular intervals ; 4. *Encircling high land*, but separated from it by a deep concentric channel, with several openings into the main sea. To account for these peculiar configurations, which are very persistent over the whole of the Pacific, various hypotheses have been advanced, all more or less involving the idea of subterranean movements, to which that region is known to be subjected. *First*, Circular reefs or *atolls* are supposed to be founded upon submerged volcanoes—the edges of the crater forming a basis for the coral, and its interior depth the lagoon. The coral islands of the dangerous Archipelago are all of this kind, and consist of circular belts from 400 yards to one mile across the ring, which always enclose a lagoon. They are seldom raised more than four or six feet above the water ; are abrupt towards the ocean, which rapidly deepens to more than 100 fathoms ; vary from two or three to 150 miles across ; and are intersected by deep channels, which allow a free communication between the ocean and the lagoons. The bottoms of the latter are often strewn with dead shells and fragments of coral ; sometimes contain smaller reefs, and give birth to numerous corallines, sponges, and shell-beds. The subjoined engraving represents the atoll form, with its enclosed lagoon :—



Distant view of a coral island, with its enclosed lagoon.

Second, Flat or tabular reefs are founded upon some elevated portion of the sea-bottom ; they have no lagoons or channels,

but form solid islands of coral, which in progress of time become covered with sand, soil, and other debris. Reefs of this kind often exhibit lines of stratification in their mass, owing to the drifting of sand, shells, &c. over their flat surface during the time of formation. *Third*, Long narrow reefs, which are of common occurrence, are evidently founded upon submarine ridges, interrupted by irregularities and depressions—such depressions causing the channels or gaps by which they are intersected. Many of this class are of great length: Captain Flinders describes one on the east coast of New Holland not less than 350 miles, unbroken by any channel. *Fourth*, Reefs encircling high land, but separated from it by a narrow channel, indicate a submergence of the islands which they surround. At their commencement they must have been in connexion with the shore; a submergence, however, would remove them from it, inasmuch as the waters would cover them, and find a new shore farther inland. In their new position, the zoophytes would build upwards, forming perpendicular masses separated from the land by a greater or less expanse of water, according to the amount of submergence, and the abrupt or gentle ascent of the land. This class is beautifully illustrated by the reefs which encircle the islands Raiatea and Tahaa:—



Such are the general forms in which coral islands appear; though it must be observed that points of attachment are afforded by many portions of sea-bottom upon which reefs are reared after fashions the most grotesque and irregular.

305. *The extent and magnitude of coral reefs* are so great, as to be put in comparison with those of the older calcareous formations. They throng the Pacific over a space comprehended between the 30th degree of latitude on each side the equator; the Arabian and Persian Gulfs abound in the same

formation ; so, also, the Indian Ocean between Madagascar and the Malabar coast. Captain Flinders describes the great reef which follows the line of the north-east coast of New Holland as more than 1000 miles in length, in course of which there is one continued portion exceeding 350 miles, without a break or passage through it. The thickness of the mass is variable—in some instances less than twenty feet, and in others more than a hundred. Estimating the average at thirty or forty feet, and taking into account the vast length to which coral ridges extend, they constitute an amount of calcareous matter equal to any of the older limestones, the carboniferous alone excepted.

306. *The growth of coral* is by no means rapid ; for objects long submerged have been dredged up merely covered with a thin incrustation. It is stated in Captain Beechey's Expedition to the Pacific, that no positive information could be obtained of any channel having been filled up by coral within a given period, and that several reefs had remained for more than half a century at about the same depth from the surface. By others, it has been estimated that the increase of a reef is generally from four to six inches in one hundred years ; but this is little better than conjecture ; for although the growth of coral by itself be a comparatively slow process, yet, by the accumulation of shells, broken coral, and other drift, a reef may augment at a more rapid rate. Whatever the rate of growth, the process of augmentation is incessant ; and thus, in the course of centuries, have the reefs and islands of the Pacific risen above its waters. The student must not, however, confound elevation above the ocean with strict increase of coralline matter ; because there is every reason to conclude that vast areas of the Pacific are undergoing a gradual upheave, by which submarine reefs and ridges are continually being brought to the surface, and existing islands further enlarged and elevated.

SOILS.

307. *The superficial coating of the earth on which plants have grown and decayed is properly denominated "soil."* It is chiefly composed of inorganic substances—that is, of clay, sand, lime, &c.—with an admixture of decomposed vegetable and animal matter. There is scarcely a portion of the earth's crust entirely destitute of this covering, unless it be the snow-clad peaks of the loftiest mountains, the newly-deposited debris on the sea-shore, or the shifting sands of the desert. However slight the admixture of organic matter may be, its presence

constitutes soil, beneath which is the *subsoil*, comparatively or altogether without such admixture, and therefore justly classed as clay, sand, gravel, lime, or mixed earth, as the case may be. Soil subserves most important purposes in the economy of creation: without it there could be no succession of vegetation; without a succession of plants terrestrial animals could have no subsistence.

308. *The formation of soil* is of easy comprehension. Suppose a tract variously composed of clay, sand, lime, and other primitive earths to be elevated above the waters, its mass would soon become dry and compact, and being alternately subjected to the sun and showers of summer, and to the frosts of winter, its superficies would be rendered loose and friable. Over this expanse birds would fly and animals roam, mingling their droppings with the earth, and adding their carcasses and other exuvæ; the winds would carry the seeds of plants from other regions, and these springing up, would clothe patches of the waste with a scanty vegetation. Mosses, lichens, and other lowly forms would spread over the rocks and gravel, the arundo arenaria, elymus, &c. over the sands, the sphagnum and other aquatic tribes in the marshes, and grasses on the silts and richer portions. The annual growth and decay of these plants would soon form a covering of vegetable mould, enriched by the droppings and exuvæ of animals which fed upon them; and thus in process of time would the region present varieties of soil capable of supporting the highest forms of vegetation. We see such a formation every day taking place around us; *naturally*, in those districts unreclaimed by agriculture, and *artificially*, where manures are added to promote its fertility. Independent of its utility to the vegetable and animal economies, soil is of great geological importance, inasmuch as it lessens the amount of degradation to which the crust is exposed. Without the conservative influence of the turf which protects the subsoils, every shower and stream would wash away vast quantities of the loose material, whereas the lightest sand is secure from abrasion beneath the thinnest grassy covering.

309. *Though the character and variety of soils* is more the study of agriculture than of geology, it may be useful for the student to know the distinctions which have been made by recent writers on the subject. The *inorganic* portion of soils consists of what are called the primitive earths—namely, clay, siliceous sand, lime, and magnesia—and of certain saline and metallic compounds, such as common salt, gypsum, soda, potash, and the oxides of iron and manganese. The *organic* constituents are decomposed vegetable and animal matters, the progressive decomposition of which, in conjunction with

inorganic substances, air, and water, furnish chemical compounds of humus, carbon, ammonia, &c.—all of which are essential to the perfection of vegetable growth. Sand and clay being the bulky components of soils, a soil is said to be *sandy* when it contains no more than 10 per cent. of clay; a *sandy loam* if from 10 to 40 per cent. of clay; and *loam* if from 40 to 70 per cent. On the other hand, should the clay average from 70 to 85 per cent., it is denominated a *clay loam*; from 85 to 95, a *strong clay*; and if no sand be present, it is pure *agricultural clay*. The same sort of distinctions are made when lime is present in considerable abundance—5 per cent. of carbonate of lime constituting a *marl*, and 20 per cent. a *calcareous soil*. Where soils are immediately derived from the rocks beneath, they partake of the same chemical character; and where separated by layers of sand, clay, and gravel, they are still influenced in their capacities for moisture by the porous or open texture of the subjacent strata. There is thus an intimate connexion between the deductions of geology and agriculture—a connexion which will be more fully pointed out in a subsequent section.

EXPLANATORY NOTE.

ALABASTER—a white semi-transparent variety of gypsum, or sulphate of lime. It is a mineral of common occurrence, and is manufactured into ornamental vases, and occasionally into small statues. The ancients used it for ointment and perfume boxes.

MINERAL NAPHTHA is generally found of a yellowish colour, but may be rendered colourless by distillation. Its specific gravity is about three-fourths that of water; it boils at 160 degrees; and appears to be a pure hydro-carbon, consisting of 36 of carbon and 5 of hydrogen. It is highly inflammable, and burns with a white smoky flame. A liquid very similar to mineral naphtha is obtained by the distillation of coal-tar.

PROSTRATION OF TREES.—It has been stated that the trunks found in British peat-mosses are most abundantly prostrated towards the east and north-east. This is just what might be expected where the trees have been overthrown by natural forces; for not only are our most prevalent winds from the west and south-west, but our highest and most destructive gales are also from the same quarters.

CORAL.—Some varieties of this substance have long been in request for ornamental purposes—their value depending upon the size, solidity, and colour of the specimen. Black and red varieties are the most highly prized, portions of Sicilian coral having been known to bring so much as eight or ten guineas per ounce. The price, however, is extremely variable, other portions of the same mass selling for less than a shilling a pound. Regular coral fisheries are established in the Straits of Messina, on the shores of Majorca and Minorca, the coast of Provence, and in other parts of the Mediterranean. Abundant supplies are also obtained from the Red Sea, the Persian Gulf, the coast of Sumatra, &c.

SUPERFICIAL ACCUMULATIONS—CONTINUED.

EARTHQUAKES AND VOLCANOES.

310. *The effects produced by earthquakes*, in as far as elevations and depressions of the earth's crust are concerned, have been already alluded to, but the various results by which they are followed require further attention. An earthquake may produce a momentary undulation of the ground, followed by no perceptible result; it may simply elevate one region or depress another; it may be attended by a vast destruction of animal life, and the submergence of forests; it may alter the course of rivers, and produce new shores and beaches; it may create vast tidal waves, which give rise to accumulations of debris; open new springs and fissures, from which issue various products differing from those hitherto known in the district. Innumerable instances of such changes could be cited; a few, however, will suffice to convince the student of the importance of this class of geological agencies:—By the great Chili earthquake of 1822, an immense tract of ground—not less than 100,000 square miles—was permanently elevated from two to six feet above its former level; and part of the bottom of the sea remained bare and dry at high water, with beds of oysters, muscles, and other shells adhering to the rocks on which they grew, the fish being all dead, and exhaling most offensive effluvia. By an earthquake in 1819, a tract—the Ullah Bund—in the delta of the Indus, extending nearly fifty miles in length and sixteen in breadth, was upheaved ten feet; while adjoining districts were depressed, and the features of the delta completely altered. So also with the valley of the Mississippi in 1811, which, from the village of New Madrid to the mouth of the Ohio, was convulsed to such a degree as to create lakes and islands. The earthquakes of Calabria, which lasted for nearly four years—from 1783 to the end of 1786—produced numerous fissures, landslips, shifts or faults in the crust, new lakes, ravines, currents of mud, falls of the sea-cliffs, and other changes, which, taken in conjunction, afford the geologist one of the finest examples of the complicated alterations which may result from a single series of subterranean movements, even though of no great violence. In 1743 the town of Guatemala, in Mexico, with all its riches and eight thousand families, was swallowed up, and every vestige of its former existence obliterated; the spot being now indicated by a frightful desert four leagues distant from the present town. In 1692 a similar calamity overtook the town of Port Royal,

in Jamaica, when the whole island was frightfully convulsed; and about 1000 acres in the vicinity of the town submerged to the depth of fifty feet, burying the inhabitants, their houses, and the shipping in the harbour. Such examples might be multiplied indefinitely, even within the limits of the historic period; but enough has been quoted to show the extensive nature of the changes which may have been produced upon the superficies of the globe since the commencement of the current era.

311. *Volcanic forces* act in a similar manner, in as far as they elevate, depress, and break asunder portions of the earth's crust; indeed earthquakes and volcanic throes, considered as subterranean movements merely, produce precisely the same results. But volcanoes, properly so called, act in another and equally important manner in producing geological changes. They elevate the crust into long continuous ridges or mountain chains, form isolated cones, and discharge accumulations of lava, scorix, ashes, loose stones, and other igneous debris. The same effects have been produced by igneous forces in all ages, as are amply evidenced by the *granitic* rocks of the primary, and by the *trappean* eruptions of the secondary and tertiary epochs. *Volcanic* rocks represent the igneous products of the present era, and are associated with the superficial accumulations, just as the older traps are with the coal measures, oolite, and chalk strata. The granitic and trap rocks occur either as disrupting, interstratified, or overlying masses; so do the volcanic: the former cover extensive districts, and form vast mountain ranges; so do also the latter, as will be seen by an enumeration of some of the more celebrated volcanoes. In Europe there appears to be three centres of volcanic action—namely, that of the Levant, to which *Ætna* and *Vesuvius* belong; that of Iceland, represented by *Hecla*; and that of the Azores. In Asia there is abundant evidence of volcanic action on the borders of the Mediterranean, the Black Sea, the Caspian, and the Persian Gulf; while along the eastern borders of that continent there is a range not less than 5000 miles in length and 250 in breadth, including *Sumatra*, *Java*, the Eastern *Moluccas*, and the *Phillipine Islands*; the same range bearing farther northward, though less distinctly, for several thousand miles, and terminating in the volcanic cones of the *Aleutian isles*. The whole extent of the two Americas is also traversed by a volcanic range, manifesting itself by eruptions along the whole line, from the *Rocky Mountains* through *Mexico* and the *Andes*, onward to *Patagonia* and *Terra del Fuego*. The islands of the Pacific further attest the presence of similar forces; as do those—

namely, the Canaries, Cape de Verd, Ascension, St Helena, Madagascar, Bourbon, &c.—which surround the continent of Africa. In these centres of igneous action many of the volcanoes are *extinct*, others are merely *dormant*, while many are incessantly *active*.

312. *Passing over the disruptions produced by volcanic forces, some idea of their importance in adding to the rocky material of the earth's crust may be gleaned from what is stated in par. 73, and from the following quotations.* In the year 1759 the plain of Malpais, which forms part of the volcanic district of Mexico, was disturbed from the month of June till August by hollow sounds and a succession of earthquakes; and in September flames burst from the ground, and fragments of burning rocks were thrown to a prodigious height. Six volcanic cones were formed, of which Jorullo, the central one, was elevated 1600 feet above the plain, and continued burning, sending forth streams of basaltic lava till the month of February in the succeeding year. None of the other cones were less than 300 feet in height. Twenty years after the eruption, this spot was visited by Humboldt, who found around the base of the cones, and spreading from them as from a centre, a mass of matter 550 feet in height, extending over a space of four square miles, and sloping in all directions towards the plain. A subsequent eruption of this volcano took place in 1819, on which occasion the ashes discharged were so abundant, that they covered the streets of Guanajuato to the depth of six inches, although the distance of that city from the volcano is not less than one hundred and forty miles. During the eruptions of Sumbawa in 1815, ashes were carried 300 miles in the direction of Java, and more than 200 miles northwards towards the Celebes, in sufficient quantity to darken the air; they were also found floating in the ocean to the west of Sumatra, a distance of more than one thousand miles, forming a mass two feet thick, through which vessels with difficulty forced their way. The last example which we shall here notice is that of the Skaptaa Jokul, in Iceland, which took place in 1783. This eruption continued with greater or less activity during the space of ten weeks, and produced the most disastrous effects, as well as the most extensive geological changes, on the face of the island. "The immediate source," says Mr Ansted, "and the actual extent of these torrents of rocks have never been actually determined; but the stream that flowed down the channel of the Skaptaa was about fifty miles in length by twelve or fifteen in its greatest breadth. With regard to its thickness, it was very variable, being as much as five or six hundred feet in the narrow channels, but

in the plains rarely more than a hundred, and often not exceeding ten feet." If such be the magnitude of isolated and temporary eruptions, the student cannot fail to perceive how much of terrestrial change must have been produced by volcanic action even during the few thousand years of human history; and can have no difficulty in reasoning from modern igneous forces to those which exerted themselves during the trappean and granitic eras.

313. *The products of volcanoes* are commonly recognised as lava, obsidian, pumice, scorise, ashes, mud, steam, and various gases, of which muriatic acid, carbonic acid, and sulphuretted hydrogen are the most abundant. *Lava* is the name given to the melted rock-matter which issues from active craters, and which, when cooled down, forms varieties of volcanic trap, as trachyte, basalt, greenstone, and dolerite, according to the amount of felspar, hornblende, and augite which these rocks respectively contain. *Obsidian*, or volcanic glass, is a glassy lava of a black colour, nearly opaque, and scarcely distinguishable from artificial glass slag. *Pumice* is a light, porous, or vesicular rock, the vesicles having been formed by the disengagement of gases while the mass was in a state of fusion. *Scorise, cinders, ashes*, and the like, are of the same mineral composition as the solidified lava, and seem to be produced by the dissipation of the liquid mass by the explosive energy of steam and other gaseous forces. The admixture of water with volcanic ashes forms a fetid clayey mud, which sometimes bubbles out from fissures, or is ejected in currents with considerable violence. *Gaseous products* are in continual exhalation from active craters, or from rents in extinct volcanoes. *Steam* is the most abundant of these; and next in order are the *sulphurous vapours*, from which are derived those deposits of sulphur so extensively employed in the useful arts. The manner in which the rock products arrange themselves is highly instructive, inasmuch as it supplies the geologist with data to reason respecting the occurrence of igneous rocks in connexion with the older stratified systems. *Lava* issuing from active craters descends in currents from the mountain side, filling up valleys, damming rivers, covering plains, and if in the neighbourhood of the sea, spreading along its bottom, there in turn to be covered by newer sediments. *Scorise, ashes*, and other light material being showered abroad, and borne by winds often to a great distance, are scattered indiscriminately over land and sea, forming layers of considerable thickness, which under the waters are also covered by other deposits. *Lava* cools irregularly; in one place presenting trachyte of a porphyritic tex-

ture, at another passing into granular greenstone, and not unfrequently assuming a true basaltic structure. In all this the student must see repeated the same processes by which the granitic and trappean compounds were formed, the same modes of arrangement and relation to the stratified rocks; and so can reason with certainty, from what is recent and apparent, to that which is ancient and obscure.

314. *The cause of volcanoes, earthquakes, and other subterranean movements* has been the subject of several theories, but is yet by no means very satisfactorily determined. The most prevalent opinion is that which connects them with one great source of central heat—the residue of that incandescent state in which our globe originally appeared. By this hypothesis it is assumed that the crust of the earth is of various thickness, that it contains vast caverns, and is extensively fissured—primarily by unequal contraction from cooling, and subsequently by subterranean agitations. Through these fissures water finds its way to the heated mass within; this generates steam and other gases, and these exploding, and struggling to expand, produce earthquakes and agitations, which are rendered more alarming by the cavernous and broken structure of the crust, and the yielding material upon which it rests. Occasionally, these vapours make their way through fissures and other apertures as gaseous exhalations, or as hot springs and jets of steam and water, like the geysers of Iceland. On the other hand, when the expansive forces within become so powerful as to break through the earth's crust, discharges of lava, red-hot stones, ashes, dust, steam, and other vapours follow; and repeated discharges of solid material gradually form volcanic cones and mountain ranges. It does not follow, however, that volcanic discharges must always take place at the point where the greatest internal pressure is exerted, for volumes of expansive vapour press equally upon the crust and upon the fluid mass within, so that the latter will be propelled towards whatever craters or fissures do already exist. This theory of central heat is further supported by the occurrence of igneous phenomena in all regions of the globe, and by the fact that most volcanic centres are in intimate connexion with each other—a commotion in one district being usually accompanied by similar disturbances in another. The only other hypothesis which has met with countenance from geologists, is that which supposes the internal heat to be the result of chemical action among the materials composing the earth's crust. Some of the metallic bases of the alkalis and earths, as potassium, the moment they touch water explode, burn, melt, and become converted

into red-hot matter not unlike certain lavas. This fact has given rise to the supposition that such bases may exist within the globe, where, water finding its way to them, they explode and burn, fusing the rocks among which they occur, creating various gases, and producing caverns, fissures, eruptions, and other phenomena attendant upon earthquakes and volcanoes. As yet, our knowledge of the earth's crust at great depths is excessively limited; we know little of the chemical and magnetic operations which may be going forward among its strata, and we are equally ignorant of the transpositions which may take place among its metallic and earthy materials; but judging from what we do know, this theory, however ingenious, seems by no means adequate to the results produced. It is true that there occurs nothing among the products of volcanoes at variance with its assumptions; but the magnitude, the universality, and the perpetuity of volcanic action point to a more stable and uniform source—that source being the internal heat or residue of that igneous condition in which our planet originally appeared.

EXPLANATORY NOTE.

Obsidian—so named, according to Pliny, from Obsidius, who first found it in Ethiopia. It is a true volcanic glass, of various colours, but usually black, and nearly opaque. In Mexico and Peru it is occasionally manufactured into adzes, hatchets, and other cutting instruments, or fashioned into ring-stones. So closely does it resemble the black slag of our glass furnaces, that in hand specimens it is almost impossible to distinguish the artificial from the natural product. Obsidian consists chemically of silica and alumina, with a little potash and oxide of iron.

Sulphur, also known as *brimstone*, is a yellow brittle mineral product found in various parts of the world, but most abundantly in volcanic regions. For economical uses, it is chiefly obtained from Sicily, the south of Italy, and the West Indies, though many other districts could yield a profitable supply. It commonly occurs massive, and intermingled with earthy impurities; but is sometimes found crystallised, or as an efflorescence on the sides of fissures, around hot springs, and other subterranean openings. The properties of sulphur are well known: it is a simple combustible, solid, non-metallic; melts at the temperature of 226 degrees; emits a peculiar odour when rubbed; and takes fire at 560 degrees, burning with a dull blue flame of a suffocating odour. It is extensively used in medicine, and for numerous purposes in the arts, as in the manufacture of gunpowder, matches, vermilion, sulphuric acid, &c. Chemically speaking, sulphur is a very abundant product in nature, being found in conjunction with iron, copper, lead, and most of the metallic ores, being also widely diffused among the earths and rocks, as well as entering into the composition of many organised bodies. Though our commercial supplies of the mineral be principally obtained from volcanic districts, yet

it is in the power of the chemist to extract it from iron pyrites (sulphuret of iron), as stated in par. 229.

VOLCANOES which give unremitting or periodical evidence of their being the seats of subterranean fire, are said to be *active*; such as have been in a state of commotion within the historic period, but now afford no symptoms of igneous action, are termed *dormant*; while those concerning whose activity there is no historical or traditional mention are regarded as *extinct*.

RECAPITULATION.

315. Having described, as fully as the rudimentary nature of this treatise will allow, the various stratified formations, together with their associated igneous rocks, it may be of value now to take a general review of the facts established by geologists in their endeavours towards a completion of the history of our planet.

316. *Whatever may have been the constitution of the globe previous to the origin of granite, we are warranted in concluding that rocks of this class form a floor or basis upon which all the stratified formations recline. Among the granitic rocks there is no evidence of a sedimentary origin, no lines of stratification, no fossils; all of them are massive, and highly crystalline. They upheave, disrupt, and break through the overlying strata in a manner which leaves no doubt of their having been produced by igneous fusion; and such an origin is now assigned to them by almost all geologists. Had granite been a mere metamorphic rock—that is, a product derived from the fusion of sedimentary strata—some evidence of the fact must have been furnished by enclosed fragments of the strata, by localities where the fusion had not been completed, or by traces of sedimentary lines; for, in true metamorphic rocks of the secondary period, some such proofs are always present. But even supposing the fusion to have been complete in every part, there is still the question—Whence was this heat derived? And this leads the geological theorist back to the starting point, that our planet was at one time an incandescent igneous mass. Whether the earth was originally so formed, or was fused by external heat, the result would be the same—a globe of molten matter, gradually giving off its heat to surrounding space, and cooling down so as in process of time to be coated with a solid stony crust. This crust contracting and expanding irregularly, according as certain areas were good or bad conductors of heat, would produce rents, fissures, elevations, and depressions—great in as far as our standard of judging is concerned, but no more in comparison with the*

half of the globe, than the scoræ on the surface of a glass-blower's furnace. As this process of refrigeration went forward, the gases capable of constituting the atmosphere and water would condense around and upon the earth—the latter occupying the hollows of the crust, and undergoing a rapid evaporation, both by the internal heat of the mass and the external heat of the sun—and the former constituting a medium for the elaboration of vapours, rains, and other meteoric phenomena. Thus the various operations of Atmospheric, Aqueous, and Igneous agency were set in motion to modify the newly-formed crust, and to produce that long series of changes which it is the province of geology to consider. This constitutes the first era of our planet—a period when it was void of those conditions necessary to the support of vegetable and animal existence.

317. *The products of the agencies now set in motion were the gneiss and mica schist systems.* The rains which fell upon the granitic crust, the streams which descended from its mountains, and the rivers which cut their way through its gorges and valleys, would bear the abraded material to the lakes and seas, there forming layers differing little in mineral composition from the granite whence they were derived. At this period the earth's surface must have been extremely unstable, breaking down in some localities, and being upheaved in others; so that floods of molten granite would occasionally envelop the newly-deposited strata; and thus it is often difficult to separate gneiss from rocks of true granitic character. In process of time, however, the gradual refrigeration of the globe would render the configuration of its crust more stable, and so allow the sedimentary matter to be deposited not only more regularly, but also less intermingled with igneous effusions. Such a state of matters we discover in the mica schists, which are more finely laminated, and more continuous in stratification, than the subjacent gneiss. Of the sedimentary origin of gneiss and mica schist, no one who has examined these rocks in the field can have any doubt; even in hand-specimens the lines of lamination are generally well-marked; the crystals of which they are composed are fragmented and water-worn, attesting the abrading agency to which they had been subjected, while in granite every crystal is distinct and entire. It is true that the rocks of these two systems are of crystalline texture, and must have been subjected to a very high degree of heat—a temperature sufficient to form garnet within mica schist, but not so powerful as to obliterate the lines of deposit in the mass. Another and unobjectionable evidence of their sedimentary origin is afforded by the fact,

that the latter system consists of alternations of various strata, as mica, talc, and chlorite schists, crystalline limestone, and quartz. No vegetable or animal remains have been found in either system; hence the inference, that the earth at this period was not sufficiently cooled down to admit of organic development. This constitutes the second geological era—one during which the dry land and waters were alike devoid of life and vegetation; an epoch of incessant subterranean agitation, as is evidenced by the vast mountain ranges, dykes, veins, and other effusions of granite by which the sedimentary strata are elevated and contorted.

318. *The era of the clay-slate and grauwacke* which succeeded was one during which important events took place in the history of the earth. Mineralogically speaking, these rocks present an immense difference from those of previous systems. Among them the crystalline texture is faint; clayey compounds are derived from the decomposed felspar of the gneiss and granite, arenaceous rocks from the quartz, and conglomerates from the pebbles collected along the shores of the sea. Stratification is now abundantly obvious; and frequent alternations of sandstones, conglomerates, shales, and limestones prevail. All this attests great diversity of action—rivers, currents, tides, and waves; deposition in calm water, and accumulations by violent inundations. These rocks imbed the remains of lowly-organised *sea-weeds*, of *zoophytes*, and of *mollusca*. Here the geologist is, for the first time in the history of the earth, presented with organized forms—beings governed by the same laws of vitality which now regulate plants and animals. These organisms, it is true, are not of a high order; but they are as complete in their structure and kind, as perfectly adapted to the conditions under which they flourished, as the most highly-organised orders of existing nature. In all their parts we have abundant evidence of means to an end—proofs of that divine intelligence from whom nothing superfluous or incomplete ever emanates. The presence of organised beings attests a great reduction of the former temperature of the globe; the existence of a shallow sea-shore fit for the growth of marine plants; a sea-bottom adapted to the support of corals and shell-fish; and the presence of lime and other salts in the waters of the ocean, fitted for the production of such calcareous exuvæ. The deposition of the clay-slate and grauwacke forms the third geological epoch—one of comparative tranquillity and rest, capable of sustaining sea-weeds, zoophytes, and mollusca, but not yet suited to the creation of terrestrial life or vegetation.

319. *The succeeding formations—the Silurian and Old Red*

Sandstone—are more decidedly sedimentary than any of the previous systems. They are composed of sandstones, conglomerates, shales, clays, and limestones, alternating with each other in such a manner as to prove the operation of numerous agents during their deposition. At one season the rivers seem to have carried down mud and clay, at another sand of various fineness; in one locality the waves and currents produced pebbly conglomerates along the sea-shore, at another laid down the most impalpable sand, on which is often left impressed the ripple-mark of the receding tide; along some regions of the sea-bottom certain limestones were precipitated by chemical agency, in others it was accumulated by the operations of coral zoophytes. During the deposition of these rocks a change was effected upon the climate and other atmospheric conditions of the dry land, so as to enable it to sustain a scanty vegetation; and here, for the first time in the earth's history, have we evidence of *land-plants* in the remains of equisetums, ferns, and other cryptogamia. The previous *sea-weeds* become more prolific; other genera are added to the *zoophytes* and *mollusca*; and *crustacea* and *fishes* constitute a new feature in the Fauna of the globe. Respecting the land-plants, their remains are too imperfect to afford any just idea of the climate, composition of the atmosphere, or elevation of the land; one thing only is evident, that they are chiefly aquatic, and seem to have flourished in low situations by the sides of rivers, whose waters bore their detached fragments to the seas of deposit. On the other hand, the marine plants are much the same in kind with those of the *grauwacke*, only flourishing more abundantly, to furnish food to the new increase of herbivorous mollusca. The silurian seas seem to have been crowded in some localities with zoophytes and corals, for certain limestones are almost wholly composed of their calcareous secretions; and among these radiata, *encrinites* make their first appearance. New and gigantic genera are added to the shell-fish; crustacea are introduced in the form of the *trilobite*; an intermediate gradation between crustacea and true fishes in the *pterichthys*, *coccosteus*, and *cephalaspis*; and perfect fishes in the *holoptychius*, *osteolepis*, and other *ganoidia* of the old red sandstone. All this attests a great advance in the vital conditions of the globe—conditions, however, differing so much from those which succeeded, that few of the races created to live under them are to be found beyond the limits of the strata then deposited. This constitutes the fourth period of the world—one of ordinary tranquillity during the formation of the silurian rocks and lower gray sandstones; but still occasionally interrupted by volcanic action, as is evidenced by

the interstratification of igneous tufa among sedimentary compounds. The colouring matter of the red sandstones and shales seem also to bear evidence of igneous disturbance, but in centres considerably removed from the seas of deposit. Whatever may have been the amount of volcanic disturbance during the formation of these systems, there can be no doubt of its violence and extent towards their close, when they were upheaved into dry land, new mountain ranges formed, the previous strata further fractured and displaced, and the seas of future deposit circumscribed. And here the student must observe, that the igneous products have undergone a change in their composition and aspect as great as that which subsists between gneiss and sandstone. The products of previous eras were *granitic*; now they are chiefly greenstone, felspar, porphyry, amygdaloid, and other *trappean* compounds. No two sets of rocks could be more widely dissimilar, could afford evidence of a more radical change in the interior masses of the earth; and though the former are occasionally detected piercing through secondary strata, it may be received as a general truth, that by the close of the old red sandstone the true granitic era had passed away.

320. *The formation of the carboniferous system* constitutes one of the most peculiar and interesting eras in the history of our globe. Its limestones, fossil shell-beds, sandstones, shales, clays, coals, and ironstones, indicate a vast variety and complexity in the causes concerned in their production. Lakes, estuaries, and shallow seas, were the theatres of deposit; gigantic rivers, periodical inundations, tidal currents, and waves, were the transporting agents; broad river plains and deltas nourished vegetation; a wide extent of newly-upheaved continents furnished the rock debris; and new races of plants and animals were called into existence to people the scene. *Sea-weeds*, *corallines*, and *corals*, were profusely scattered along the shores of the ocean—the latter in such abundance, as to constitute beds of limestone far more extensive than the coral reefs of the Pacific. *Free radiated* animals, like the star-fish, were abundant; *shell-fish*, both fresh-water and marine, swarmed in myriads, leaving their exuvæ to form beds many feet in thickness; while new genera of *crustacea* were added to those which existed during the silurian era. Insects, vermes, and other *articulata*, appear as a fresh feature in the life of the globe; and *fishes*, of the most gigantic and predatory orders, abound in the seas and estuaries. The latter are all of the ganoid and placoid orders; and, judging from their remains, several of them seem to mark a passage from true cartilaginous fishes to sauroid reptiles. The most characteristic

organic development of this period, however, consists in the almost inconceivable growth of *terrestrial vegetation*, from which were derived those numerous beds of coal peculiar to the system. Judging from existing nature, this vegetation was chiefly of a tropical character—palms, pines, tree-ferns, cactaceæ, canes, equisetums, reeds, rushes, and allied orders; but for many there is no approaching analogue among existing plants. Most of them are of gigantic size, and indicate rapid growth. Every plain, and swamp, and hill-side seems to have been choked with their luxuriance, thus evincing conditions of temperature, moisture, soil, &c. more favourable to vegetable growth than the world has ever since experienced. Still, however, with all this verdure—this diversity of hill and plain, river, lake, and estuary—this exuberance of marine life, the earth was a luxuriant desert, if we so speak, void of terrestrial vitality. This constituted another cycle in the earth's history—a period of excessive vegetation, but only of ordinary tranquillity, as we find proofs of igneous agency more or less displayed throughout the entire formation. The subterranean fires were, however, only smouldering to renew their activity, to upheave into dry land the important products of the carboniferous strata.

321. *The era of disturbance which succeeded was that during which the new red sandstone and magnesian limestone were deposited.* Before their commencement, and just at the close of the coal-forming period, a magnificent display of subterranean agency took place. The hills upon which the mountain limestone reclines, the conical and isolated elevations of the coal measures, together with all their fractures, dykes, and upheavals, were produced by these forces. Every coal-field bears ample evidence of their effects; they seem to have continued in activity over a long lapse of years, during which the previous luxuriance of vegetation passed away, together with most of the zoophytes, mollusca, and fishes which had peopled the waters. The formation of new strata was not, however, suspended by these disturbances; new rivers carried down to new seas of deposit sand, clay, and mud; but the sandstones and shales formed by these materials are not like those of the coal measures. They are all highly coloured, imbed few or no remains of plants, contain deposits of gypsum and rock-salt, and alternate with magnesian limestones. All these facts point to the prevalence of volcanic influence—the red colouring matter, the local aggregations of rock-salt, the peculiar composition and texture of the magnesian limestone, are its immediate products. As these disturbing influences passed away, creative energy began to be exerted anew; and before the

close of the new red sandstone epoch, many new genera of fishes and *true aquatic reptiles* were called into being.

322. *The period of the lias, oolite, and chalk* was one of restored tranquillity. The strata, with a few limited exceptions, are eminently marine and estuary, deposited in quiet waters, and undisturbed by igneous agitation. Had we a map of the globe at this epoch, it would present a number of islands and low continents surrounded by comparatively shallow seas; the land supporting a tropical, but by no means exuberant vegetation, and the waters swarming with shell-fish, fishes, and reptiles. An atmosphere such as we now enjoy, a tropical temperature, and abundance of moisture, were the conditions under which new tribes of palms, ferns, cycadæ, conifera, and a few dicotyledonous trees flourished; and under which chambered shells, naked cephalopods, sea-urchins, star-fishes, new bivalves, ctenoid and cycloid fishes, numerous gigantic *reptiles*, *marsupial mammalia*, and *monkeys*, were called into existence. In all these forms we discover a nearer approach to existing nature than was made by the Fauna and Flora of previous eras; and yet few, if any, of the genera outlived the chalk formation. The deposition of the oolitic and cretaceous systems constitute another epoch in the history of our planet during which many of its inhabitants died out, and were succeeded by other races better adapted to its progressive conditions. The period was eminently one of rest, distinguished only at its termination by a few local disturbances.

323. *The tertiary strata* were deposited under conditions still more closely allied to those of the present day. With the exception of gypsum and certain limestones, the gravels, sands, marls, and clays are scarcely distinguishable from those of recent times. They seem to have been formed in estuaries and shallow seas, which at certain seasons were cut off from the influence of salt water, or at least were so situated that fresh water was then the predominating agent. None of the basins of deposit are of great extent; they generally occupy situations still flat, and differing little in point of level or configuration from existing seas. The earth at this period appears to have spread out in vast savannahs, abounding in verdure, and to have been clothed with grasses, shrubs, and trees scarcely different from living orders. *Mammalia*—herbivora and carnivora—of the most varied forms and sizes now peopled the surface, in all of which we distinguish the prototypes of existing genera. *Birds* are also added to the list of terrestrial inhabitants, and such as have been found are identical in form with those now around us. The shell-fish bear so close a resemblance to those of the present seas, that many of them are identical in

species. The fishes are chiefly of extinct genera, but otherwise closely allied in their forms and mode of life to modern families. Whales, walruses, seals, turtles, crocodiles, are now numerous and indubitable; so that, all things considered, the tertiary era brings us to the confines of existing conditions. This epoch was terminated by a wide-spread and general disturbance, by which the dry land and ocean received their present configuration. This disturbance was accompanied by an almost total destruction of the terrestrial Fauna and Flora; by a decided change of temperature in the regions where the tertiary beds were deposited; and by the production of an accumulation (diluvium) over the greater part of Europe at least, which forms a boundary between the tertiary and current epochs not to be mistaken. With this system the subterranean fires cease to discharge trappean rocks, which had been the invariable products of every igneous agitation from the dawn of the silurian period. It is true that on a small scale there are many of the tertiary traps undistinguishable from the products of modern volcanoes; but, judging them by their general relations and composition, there is as wide a difference between the igneous rocks of the current epoch and the trap, as there is between the trap and the older granitic compounds.

324. *The current era* is that lithologically represented by those superficial accumulations of gravel, sand, clay, marl, peat-moss, shell-beds, coral-reefs, &c. with which every one who moves beyond his own dwelling must be to a certain degree familiar. Many of these accumulations are of great antiquity, and, both in their mineral and fossil characters, blend with the tertiary strata. One fact to be observed respecting the whole of them is, that they are loosely and irregularly scattered over the surface, and have been evidently deposited since the crust received its present configuration. Still, it must be borne in mind that there is no such thing as geological rest—the atmospheric, aqueous, igneous, and organic agencies are incessant in their operations; so that what we denominate “an era,” is, in fact, a mere series of progressive movements, whose results present as many points of similarity as will admit of their being classed under one category. Even since the present order of things was established, great changes have been effected; portions of dry land have been submerged, and portions of sea-bottom raised above the waters; lakes have been silted up, rivers changed from their courses, and mountains formed; while organic agency has produced peat-mosses and coral-reefs of astonishing magnitude. We have seen that the Fauna and Flora of other epochs

successively died away with the change of conditions under which they flourished; and so the commencement of the current era was marked by the creation of new orders suited to its peculiar conditions. These are the various races of plants and animals now existing—subjected to the same laws of vitality, but differing in habits, form, and kind from those of other geological cycles. Formerly, the orders, genera, and species were few, with an immense number of individuals under each species; now, individuals are less numerous, while the species, genera, and orders are infinitely more varied and complicated. As far as can be inferred from the discovery of fossils, there has evidently been a progressive development of vegetable and animal life; not progressive in point of perfectitude—for the zoophyte of the silurian seas is as complex and perfect in its structure as those of the Pacific—but progressive inasmuch as higher and more varied orders were successively called into being. This view, borne out by all that has been witnessed in the stratified systems, is confirmed by the current era, which claims for itself still more highly-organised orders of being—these orders crowned, moreover, by the creation and distribution of MAN. In none of the older formations were found any remains of man or his works; these are confined to the most recent and superficial accumulations—to masses of volcanic scorize, peat-bogs, and river-sands.

325. *The history of the earth* thus presents a long series of mineral and vital gradations, as yet but imperfectly interpreted by geology. The stratified formations, from the gneiss to the existing surface, bear evidence of these gradations, both in their composition and mode of aggregation; so also do the unstratified rocks—the granitic, trappean, and volcanic compounds—by the order in which they succeed each other. On the other hand, plants and animals rise, as it were, from the simple zoophyte to man himself, appearing at successive eras, as new conditions permitted their development. As system gradually merges into system, so the Fauna and Flora of one period seem to live into that of another, there being always certain races which serve as links of connexion between succeeding eras. This idea of gradation implies not only an incessant onward change among the rock materials of the earth, but also that certain races of plants and animals must be perpetually dropping out, as links from the great chain of animated nature. And such is the fact even with respect to the current era. The mammoth, mastodon, megatherium, and other huge pachydermata which passed from the tertiary to the modern epoch, have long since become extinct, leaving their bones in the clays and gravels of our valleys. The elk, bear, wild

boar, wolf, and beaver, are now extinct in Britain; and what takes place in limited regions, must also occur, though more slowly, in wider continents. The dodo of the Mauritius, the *dinornis* and *apteryx* of New Zealand, are now matters of history; and the same causes which led to their extinction seems hurrying onward to the obliteration of the beaver, ostrich, kangaroo, and other animals whose circumscribed range of existence is gradually being broken in upon by new conditions. Such facts as these, taken in connexion with the numerous superficial changes produced by rivers, lakes, seas, peat-beds, coral-reefs, earthquakes, and volcanoes, have led to speculations as to the conditions which yet await our planet.

326. *Respecting the future history of the globe*, it were vain to offer any conjecture. Subjected as it is to the numerous modifying causes previously described, we know that vast changes are now in progress, and that the present aspect of nature is not the same as that she must assume a thousand years hence. But what may be the character and amount of these changes, what the new conditions brought about by them, or what the races of plants and animals adapted to these conditions, we have no means of determining. This only we are assured of, that whatever vicissitudes may affect the globe, they will be tempered in perfect accordance with the happiness of organised existence: that Supreme Intelligence which has maintained the past will continue to protect and superintend the future.

IMPORTANCE OF GEOLOGY.

327. The object of the science being to ascertain the nature of the materials composing the earth's crust, their mode or arrangement, and the causes producing that arrangement, it has at once a *theoretical* and *practical* importance. The former consists in that impetus which it gives to intellectual activity, the wholesome discipline which it confers on the reasoning faculties, those exalted notions of creation which it conveys, the sounder convictions of man's relation to external nature which it imparts, and in the thousand proofs which it establishes of a divine and superintending intelligence. The latter, on the other hand, arises from the economical benefits which it confers on civilised life; from the aid which a knowledge of its deductions affords to the arts of mining, engineering, architecture, and agriculture.

328. *In its philosophical and speculative importance, geology* is second to none of the natural sciences. Depending for

an accurate solution of its problems upon mechanics, chemistry, botany, and zoology, it takes a wider range of investigation than any other individual science; indeed, as a history of the earth, it may be said to embrace the total field of human research. Its study, therefore, calls into activity not only the observing powers to note what actually occurs, but the reasoning faculties to account for the source and mode of occurrence. It is thus liable to be encumbered with the absurd and fanciful theories of imperfect knowledge—theories, however, which gradually disappear before the light of more accurate observation and sounder reasoning. Though essentially aided by the other sciences, it has not left the assistance altogether unrepaid; but has afforded numerous suggestions to the chemist, and thrown additional light on the study of plants and animals by its peculiar fossil forms, which replace, as it were, the lost links of vital gradation. But the discipline which it confers on the reasoning powers is further enhanced by the intellectual pleasure which its investigations afford. The study of existing nature is confined to what is recent and obvious: geology takes a bolder flight, and reveals the successive conditions of the world to the remotest periods of time; and as each era, with its peculiar forms of life and vegetation, is unfolded, what research could be more fascinating or instructive? As in existing nature everything is impressed with proofs of divine wisdom, so in the revelations of geology every fact teems with evidence of the ceaseless agency of the same upholding power.

329. *The practical or economical value of the science* refers more especially to the art of mining, to the construction of roads, tunnels, canals, harbours, buildings, &c. and to the improvement of agriculture. In *mining*, a knowledge of geology is essential at every step. If the product sought after be coal or ironstone, the geologist knows the position which these strata occupy in the crust of the earth, the nature of the rocks usually associated with them, the kind of fossils imbedded, and can therefore direct the miner with unerring certainty. For want of this aid, vast sums of money have from time to time been expended in search of these minerals—the parties being misled by fragments of black schorl among the primitive rocks, carbonaceous shales amid the grauwacke, or by thin lignitic beds amid the lias and oolite. Now, the practised geologist knows that coal, as a distinct formation, does not exist previous to the carboniferous era, and therefore would have warned against the folly in sinking shafts in the clay-slate or old red

sandstone; he knows, also, that after the commencement of the new red sandstone, coal in workable beds ceases to be found, and that lignite, jet, and brown coal are mere local and insignificant deposits. Besides determining the position in which coal, ironstone, and other useful strata occur, geology can direct the miner through all those obstructions occasioned by faults, dykes, slips, and the like; for even these, irregular as they seem, bear certain evidence of their direction—upthrow or downthrow—which the experienced eye can readily detect. As with the minerals of commerce which occur in strata, so to a certain extent with the ores of lead, copper, tin, silver, and gold which are found in veins and lodes. These veins follow certain courses in relation to the great axis of elevation with which they are associated, are interrupted by cross dykes and veins, are thrown up or down by dislocations—all of which an experienced geologist can determine and map out, so as to save much fruitless waste of labour and capital.

330. *The importance of geology to the civil engineer and architect* is so obvious, that the fact requires little illustration. Possessed of a well-constructed lithological map, on which are delineated the various kinds of strata, their dip, direction, and other particulars, the engineer has a safer and cheaper guide for his direction than the scattered data of the boring rod. He sees at once the nature of the rocks through which his work has to pass—whether common road, railway, or canal; can estimate with certainty the expense of construction, and avail himself of minerals which he knows must lie in the vicinity; while one ignorant of geological truths would blindly pass by such advantages. In fixing a line of road or railway, the informed engineer will avail himself not only of facilities for present construction, but calculate, from his lithological knowledge of the district, for the future benefit of those concerned in the undertaking. In the case of canals, moreover, where retention of water is indispensable, the geologist can effectually aid in the selection of a route, by attending to the nature and dip of the strata, and to the fractures and dislocations to which they have been subjected. He is enabled, from his knowledge of the rocks and their positions, not only to prevent waste of water, but to select a route where fresh supplies can be readily obtained from below. As with roads and canals, so with tunnels, docks, Artesian wells, and other undertakings commonly intrusted to the civil engineer. It is true that such works may often be satisfactorily enough completed without the aid of geology, but undoubtedly a knowledge of its deductions will materially assist,

by conferring a certainty and security on what would otherwise be a mere system of trial and error. The assistance which geology brings to the architect is not quite so obvious; as actual experiment is, after all, the best and only test of a rock's durability. However, by observing the effects of weather, water, and the like, on strata exposed in natural sections, he can readily determine as to their fitness for any particular structure. The amount of waste experienced by ancient buildings is also another safe and valid test; and it is the travelled geologist, and not the mere builder, who can point to the locality, nay, to the very stratum, whence the stones of these buildings were obtained. Thus, both directly and indirectly, the science is brought to bear upon architecture; a fact fully appreciated by the legislature in its appointment of a commission, composed in part of geologists, to determine the rock most suitable for the structure of the new houses of parliament.

331. *The assistance which geology is calculated to confer on the science of agriculture*, constitutes one of the most apparent features in its economical importance. All fertile soils consist of two classes of ingredients—organic and inorganic; the former derived from the decomposition of animal and vegetable matter, the latter from the disintegration of the subsoil or rocks beneath. Without a certain proportion of organic matter, no soil can be fertile; but it is equally true, that without a due admixture of inorganic compounds, all attempts to improve it will be fruitless. These compounds are chiefly clay, lime, silicious earth, and magnesia, with certain salts of iron, manganese, potash, and soda—all of which are obtainable either from the igneous or sedimentary rocks, or from the superficial accumulations formed by their debris; and the farmer can at once effect a permanent improvement on his land by supplying the particular ingredient in which his soil may be deficient. To do this, however, he requires to know not only the composition of the most prevalent rocks, but also the precise spot which they occupy; in other words, he must be able to comprehend the language and delineations of a geological map of his own country. Besides this admixture of inorganic substances, there are other conditions necessary to fertility; namely, facilities for drainage, capability of retaining moisture, the innocuous nature of the subsoil, and power of absorbing and radiating caloric. Soil overlying trap and limestone requires less drainage than that covering the coal measures, saliferous marls, or wealden, because the former rocks are full of fissures and joints, while the latter are chiefly tenacious and

unbroken clays. Again, land of itself dry and friable may be rendered wet by springs which arise along some line of dislocation. The farmer acquainted with the deductions of geology would cheaply lead off these springs at their source, while he who was ignorant would laboriously furrow-drain his whole field, and find, after all, that his was the less effectual method of the two. Such are mere indications of the assistance which geology is calculated to confer on agriculture—an assistance very apt to be overrated, unless the farmer at the same time avail himself of the discoveries of chemistry and vegetable physiology.

332. *It must not, however, be supposed that the science is of practical value only to the miner, engineer, architect, and agriculturist; every individual is liable to be more or less assisted by its deductions. The capitalist who speculates in land, the agent who effects sales, the statistician, traveller, and explorer, may all reap direct advantage from the same source. Take, for example, a case of emigration:—Two individuals, possessed of equal capital, set out, say to New Zealand or to the Far West of North America. The one ignorant of geology fixes upon a locality characterised by the beauty of its scenery and the fertility of its soil; the other skilled in the science decides upon a long-rejected lot, of bleak and barren aspect, but rich beneath in coal, limestone, iron, copper, or lead, which his geological knowledge at once enabled him to detect. The former pays a high price for his land, and yearly toils over it to reap therefrom a remunerating harvest; the latter obtains his despised territory for a mere trifle, makes his fortune in the course of a few years, and when roads and canals are constructed around him, re-sells his property for fifty times its original purchase-money. Such instances are by no means of rare occurrence. Even our own country can furnish examples where estates, sold under ignorance of their mineral value, brought only ten or twenty thousand pounds, for which, in less than a dozen years afterwards, an offer of ten times that amount was rejected.*

333. *The advantages resulting to civilised life from the cultivation of geology must be rendered sufficiently obvious even by the above hasty and imperfect outline; and yet it is scarcely half a century since it was recognised as a legitimate branch of natural science. Previous to that period it was obscured by absurd theories, which drew down upon it the imputation of being a visionary and dangerous pursuit; now, by the cautious industry of its cultivators, it is established as one of the most important of human acquirements. It is taught in our schools and colleges, disseminated by treatises*

and from lecture-rooms, and especially fostered by every enlightened government. Like most other sciences, it has still a wide field of research before it, many difficulties to overcome, and prejudices to remove; but, linked in connexion with all that is valuable and interesting to man, there is little apprehension for the successful attainment of its object—a complete physical history of the planet we inhabit.

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THE END.

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